Searching for the Higgs

a personal view on the prospects

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LBL Seminar Berkeley

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Motivations and Caveats

Why another Higgs talk?

- things have changed over the last months
- .... and it is positive for once
- new plan for the Tevatron running: extend by 3 years?
- updates to the LHC schedule are looming

What is so personal about the view?

- some of the things I am going to say are still speculations
- some of the pictures are a little biased

What hats is the speaker wearing?

- I am a active CMS member about to become the Higgs convener for the next two years
- I am also still active on CDF

Outline

The Standard Model of Particle Physics

- what is it and what is missing?
- experimental data
- what do they tell us?
- the (simplest) Higgs boson

Hunting the simplest Higgs

- production mechanisms and decay channels
- status of Tevatron searches and the prospects

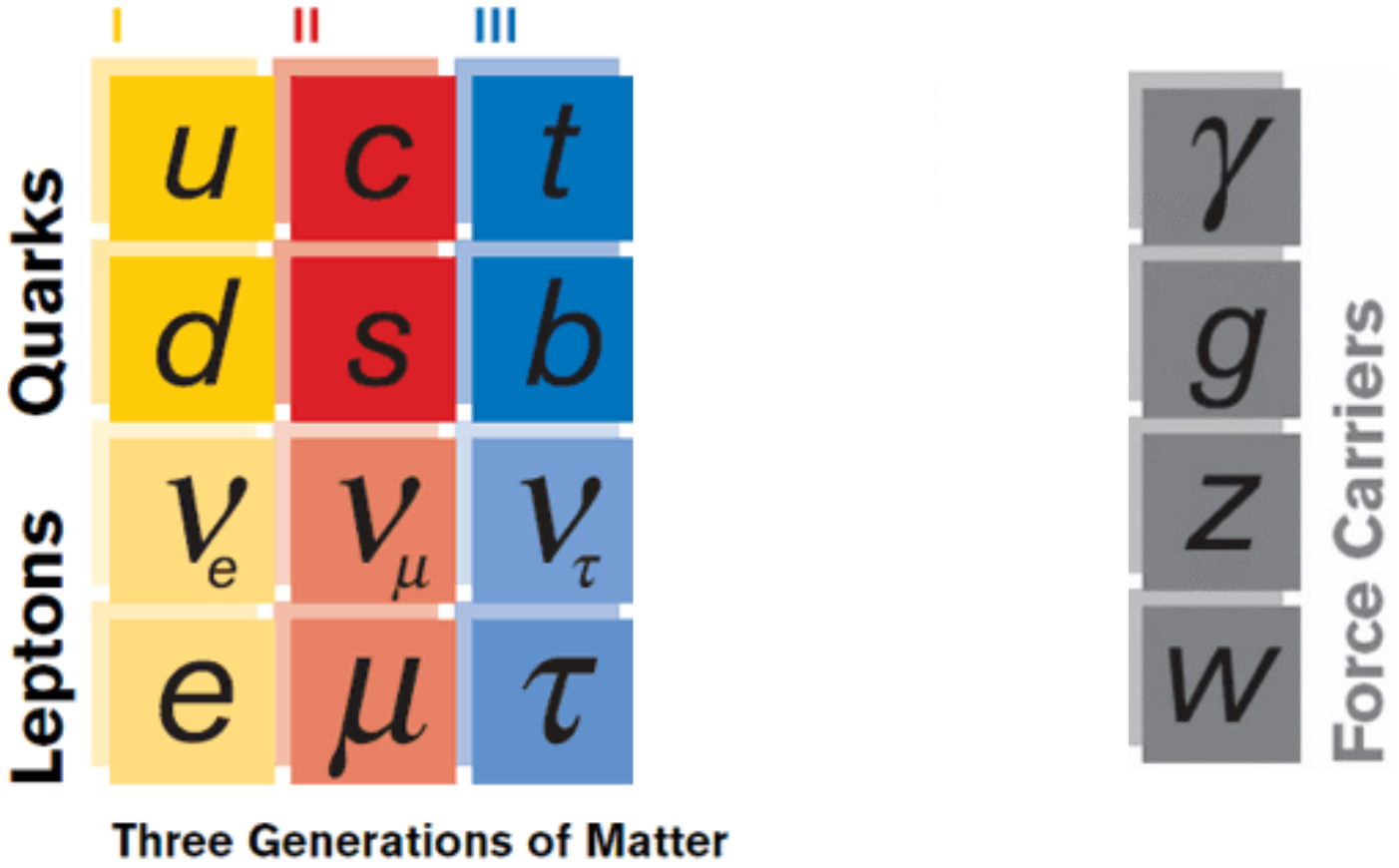
Machine (LHC) and detectors (ATLAS/CMS)

- where are we and what is the schedule
- analysis highlights
- Higgs projections

Conclusions

The Standard Model of Particle Physics

Building blocks: matter (fermions), forces (bosons)



Simple Lagrangian formalism describes this very well but only for massless particles....

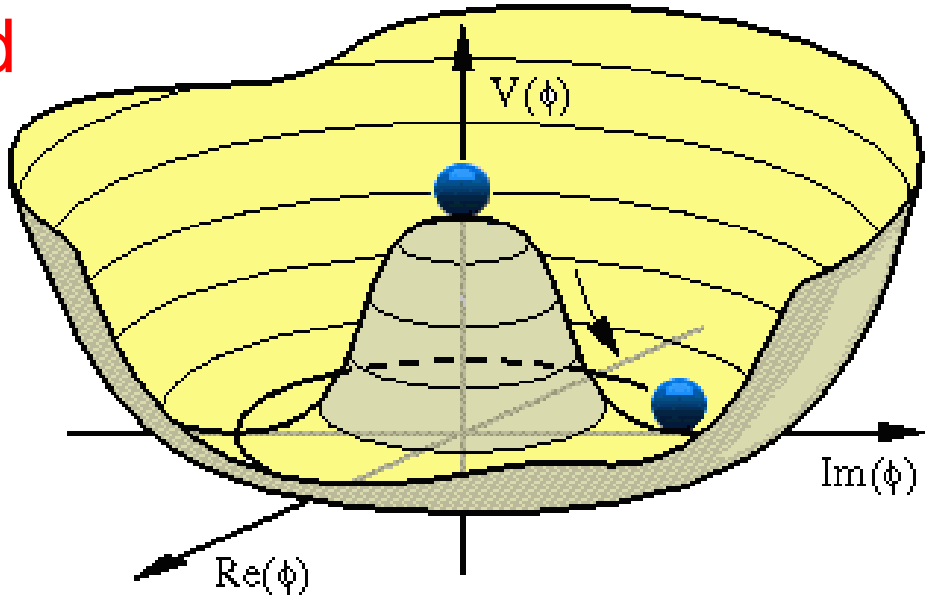
The Standard Model of Particle Physics

How do particles acquire their masses?

- hand inserted mass terms destroy gauge invariance (local)
- need gauge invariant mechanism to generate mass terms
- Higgs mechanism is the simplest way to do it

The Higgs mechanism

- introduce additional scalar field (a new scalar particle)
- modifies derivatives
- additional terms with mass appear
- vacuum expectation value ≠ 0
- particles move through field which gives them mass
- no experimental evidence, yet



Higgs Particle: Pros and Cons

The mystery of mass

- can be resolved with one scalar Higgs boson

What is good about it?

- resolves fundamental problem of mass
- nature tends to be economic: few particles
- model makes very precise predictions: decay kinematics (scalar), couplings, cross section, cross section ratios ....
  - only one parameter to vary: m_H
  - search can be very well targeted
  - similar mechanisms for example SUSY, partially covered

What is not good about it?

- no physics beyond Standard Model, we like new things
- fundamental problems of Standard Model remain

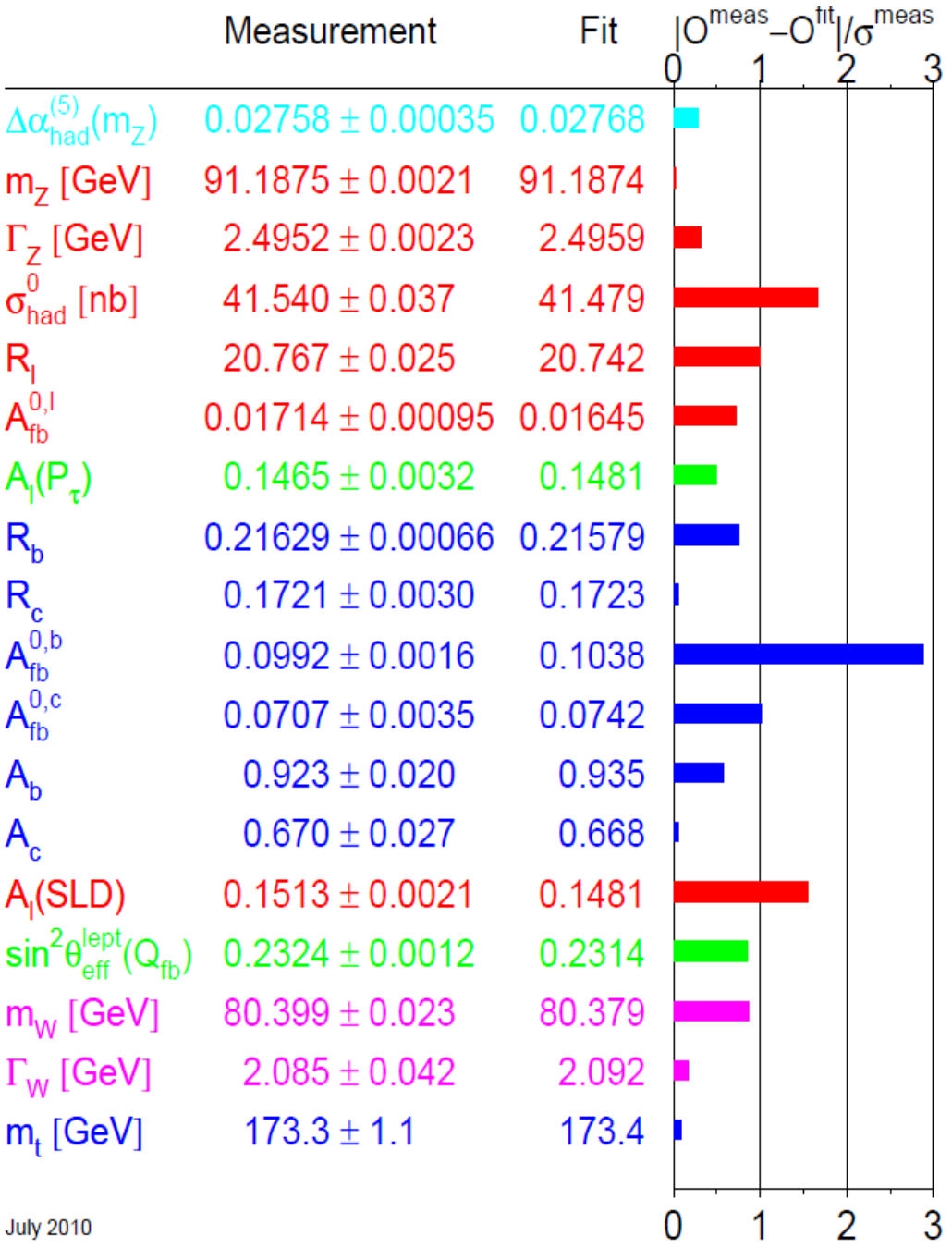
The Standard Model: Measurements

Experimental data

- LEP, SLC
- Tevatron
- Neutrino experiments
- ....

Measurements

- over a thousand individual measurements combined
- very different accelerator and detector setups
- decent agreement with SM



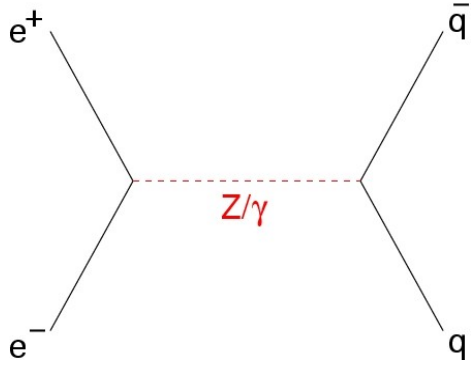
The Standard Model: Higgs Constraints

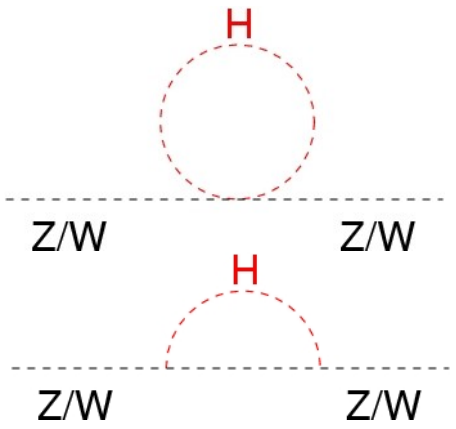
Direct searches

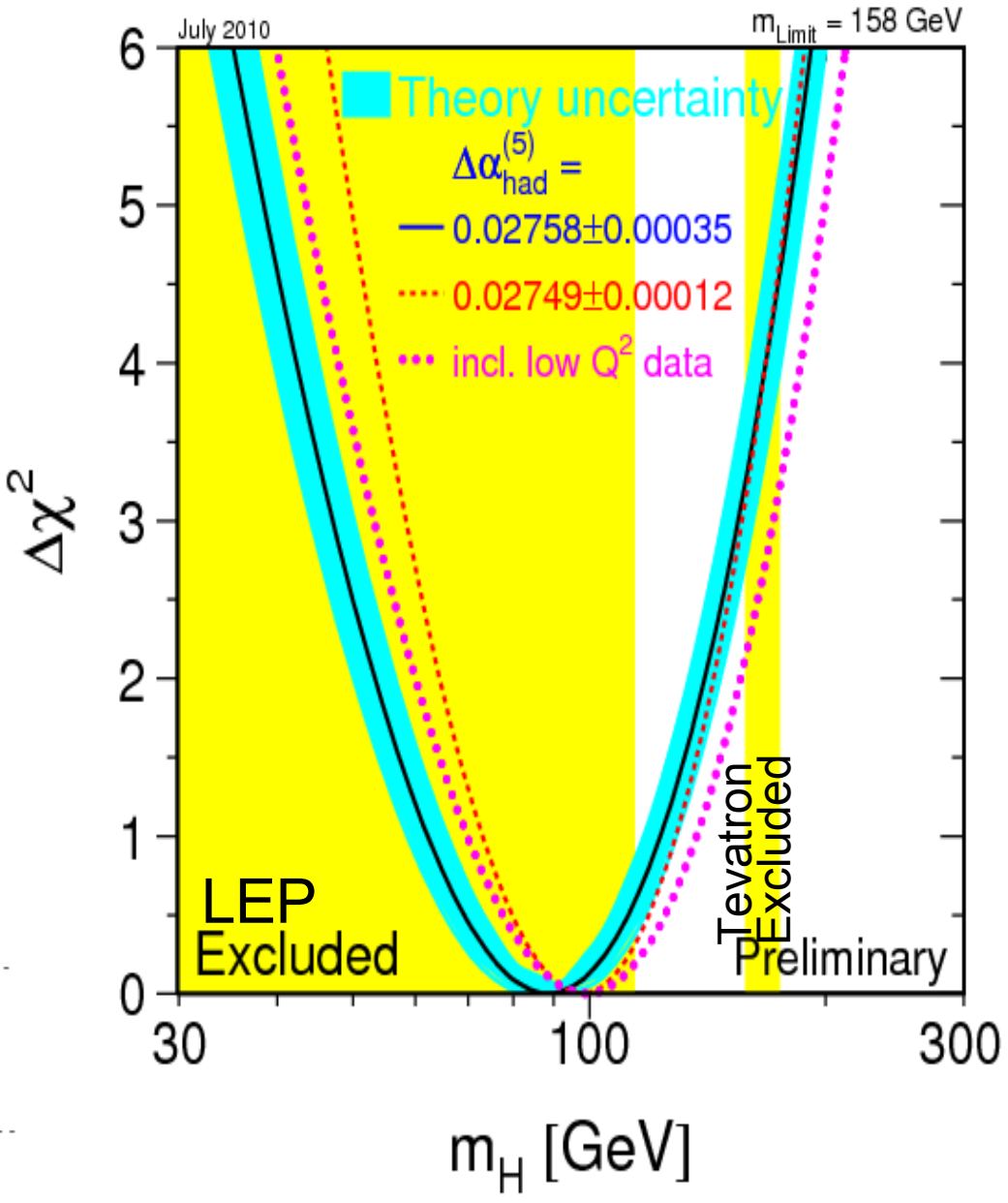
- nothing found
- Higgs boson too heavy

What precision data tell us

- radiative corrections modify lowest order processes
- Higgs present in virtual loops
- modifies observables







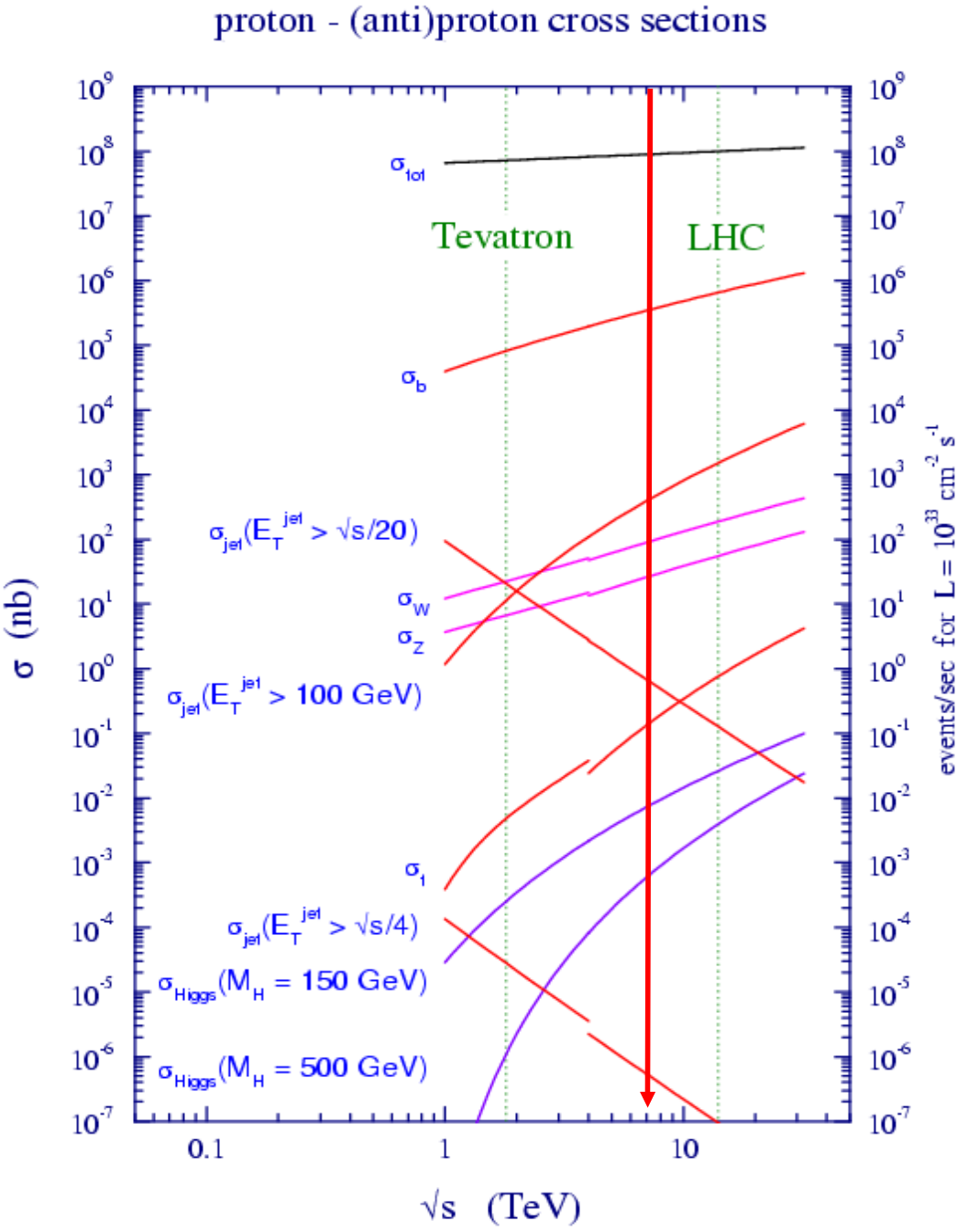
Higgs Hunting Basics

Physics processes

- production relative to σ_{tot}:
  - *bb* at 10^{-3},
  - $W \rightarrow \ell\nu$ at 10^{-6} and
  - *Higgs* (m=100 GeV) at ~10^{-11}
- 32 MHz beam crossing, only about 300 Hz tape writing: $1/10^5$
- fast and sophisticated selection process essential: trigger

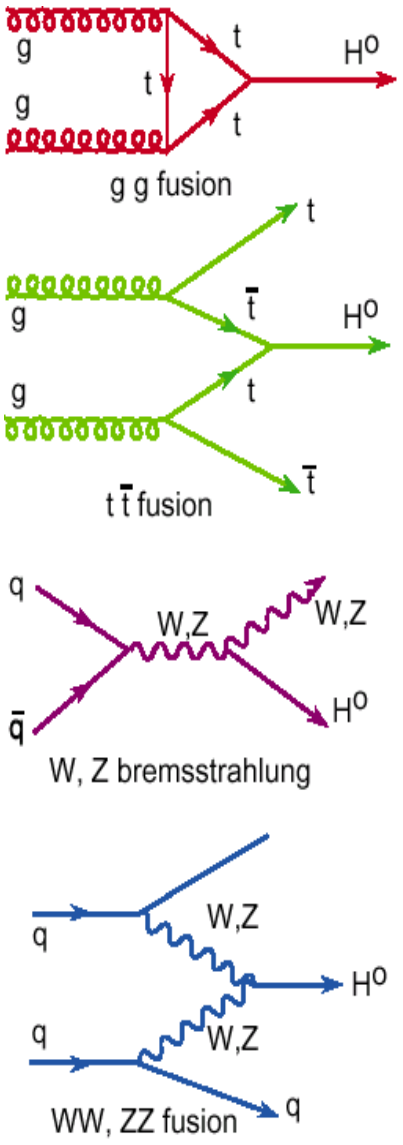
Trigger

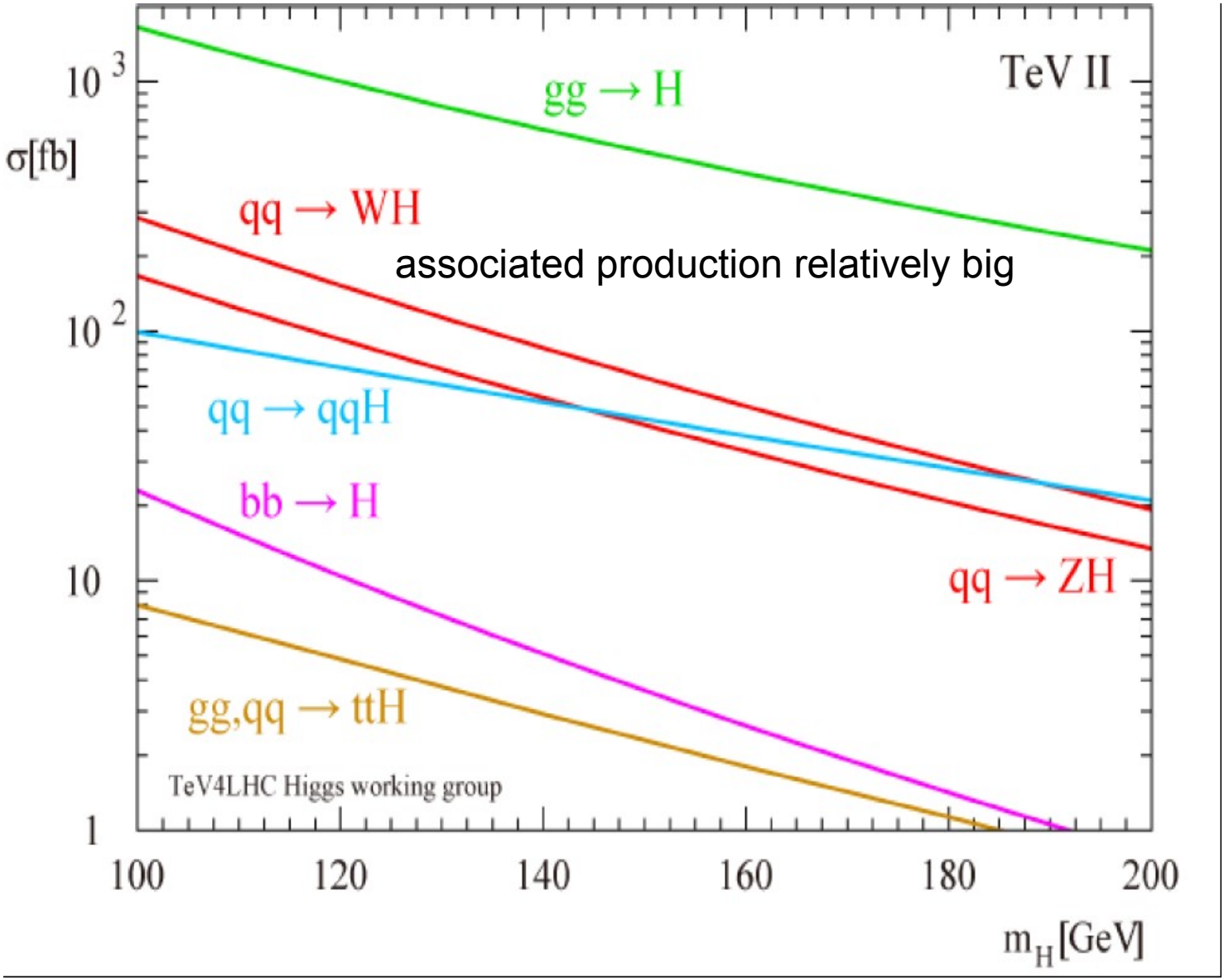
- trigger has to work: otherwise no useful data registered
- already in first data taking: rate enormous and trigger important
- core trigger organization: use electron, muon, jet and energy signatures



Higgs Production at the Tevatron

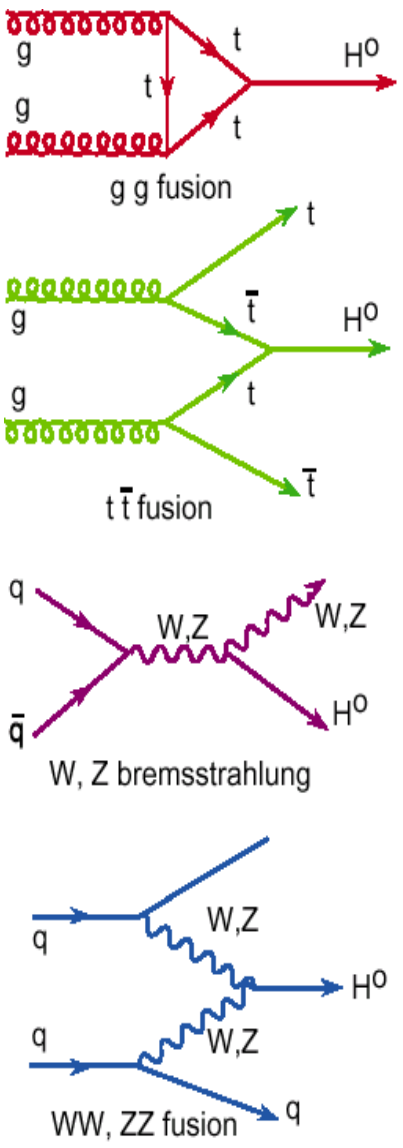
Higgs production in proton-antiproton collisions

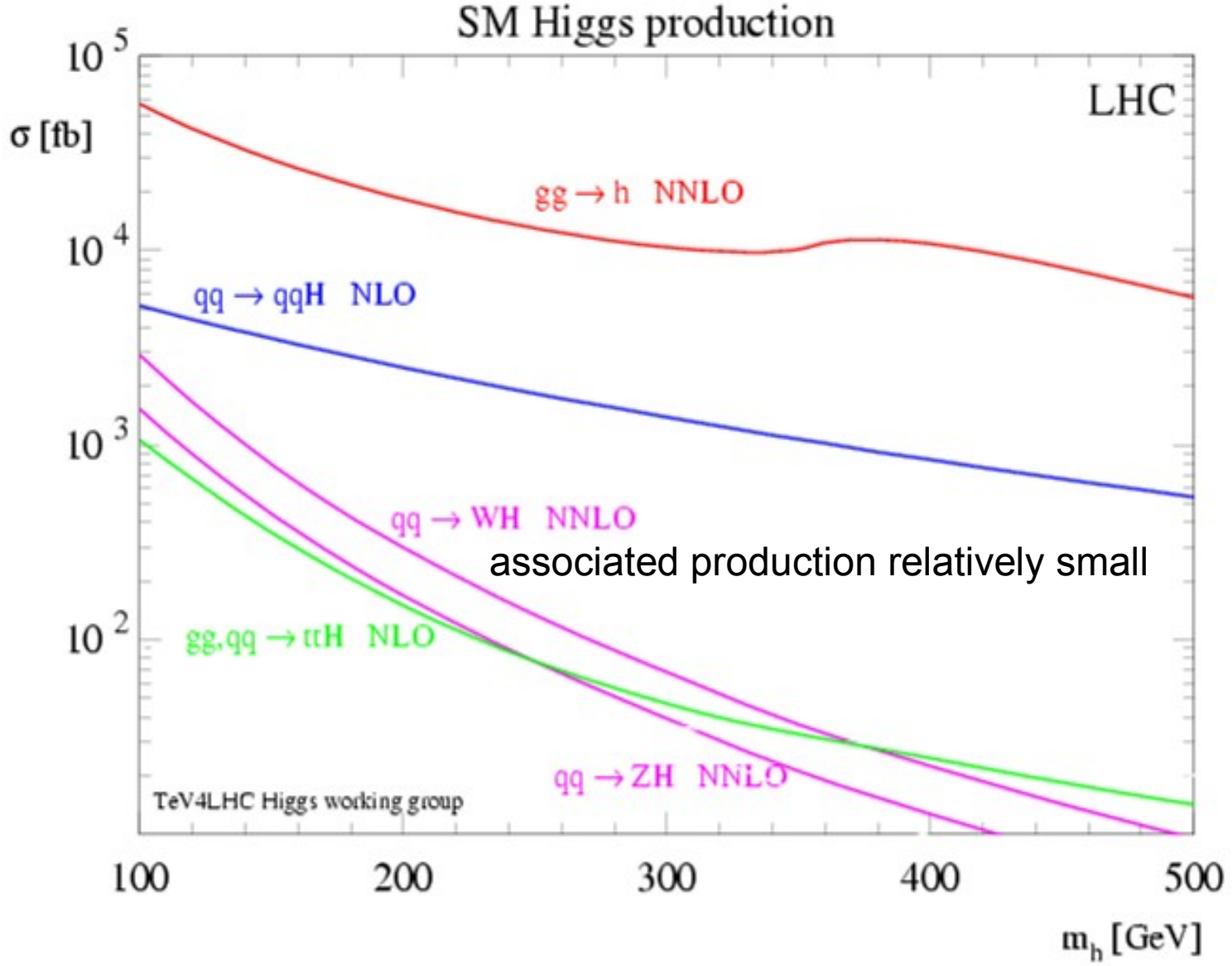




Higgs Production at the LHC

Higgs production in proton-proton collisions

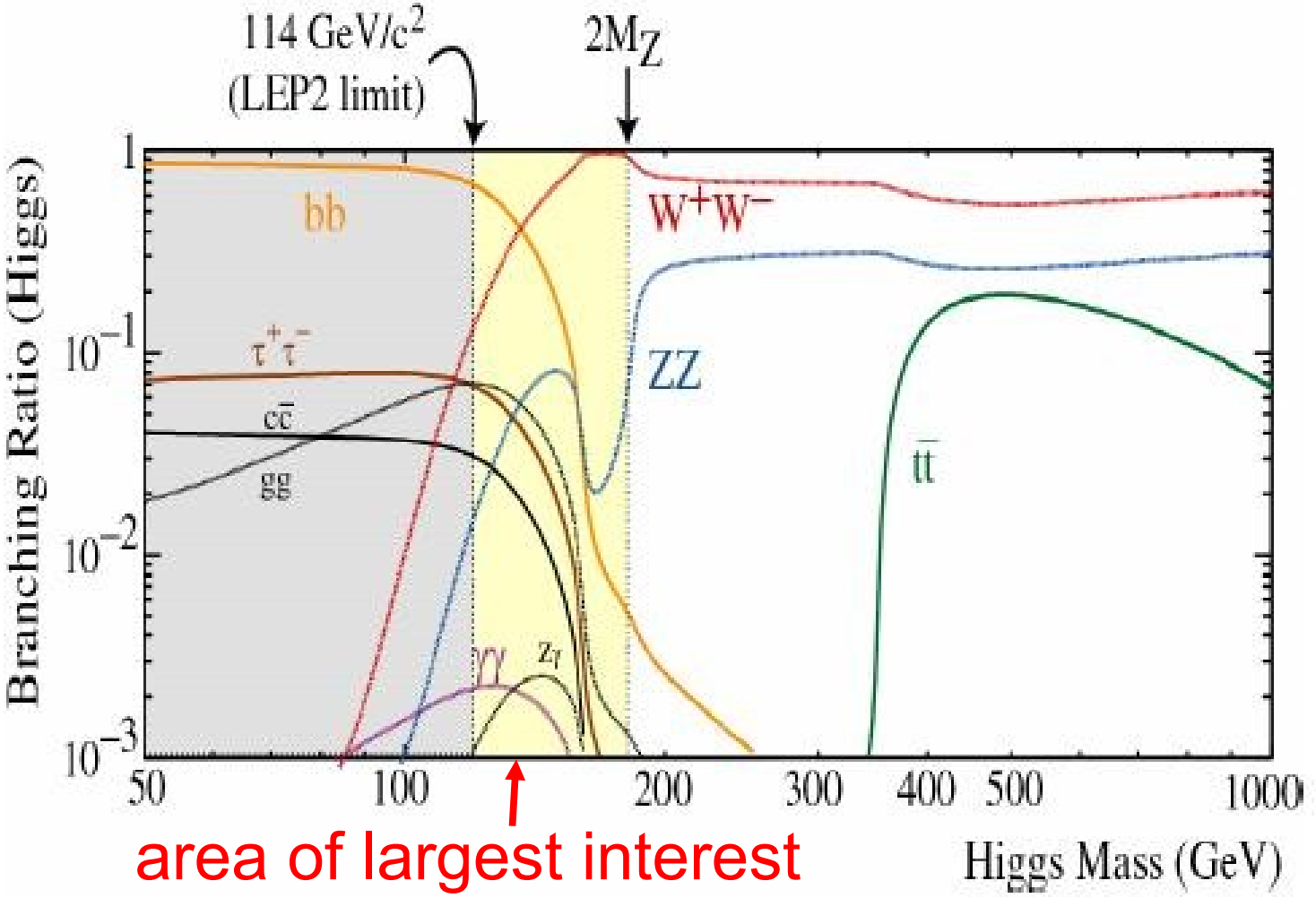




associated production relatively small

Higgs Decays (Tevatron/LHC)

Higgs decay channels, Higgs couples to mass



area of largest interest

$\Gamma_{Hff} \sim m_f^2$

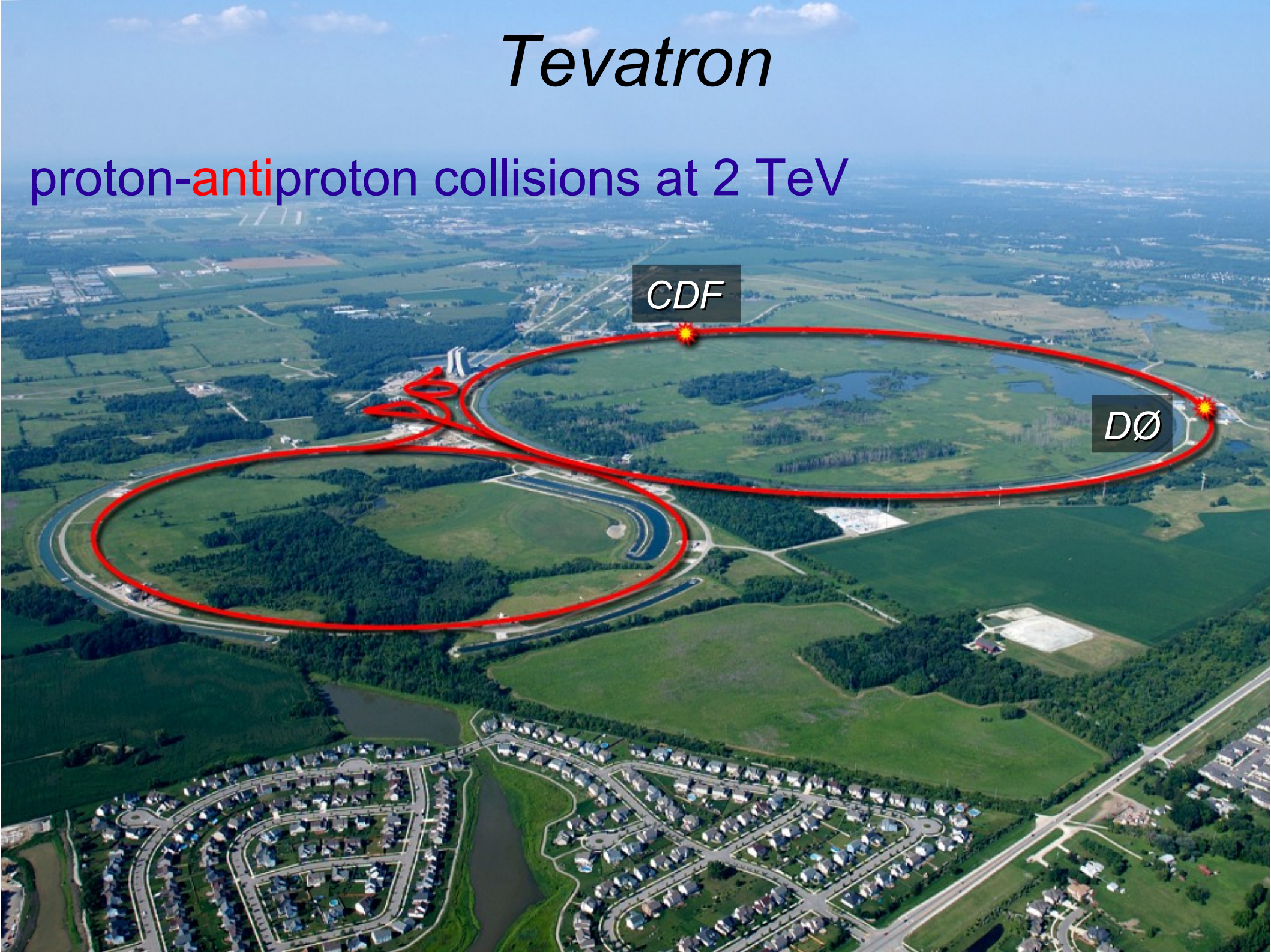
$\Gamma_{HVV} \sim m_V^4$

Messy: many channels, many subsequent decays *etc. etc.*

- common feature: leptons/photons essential for any search

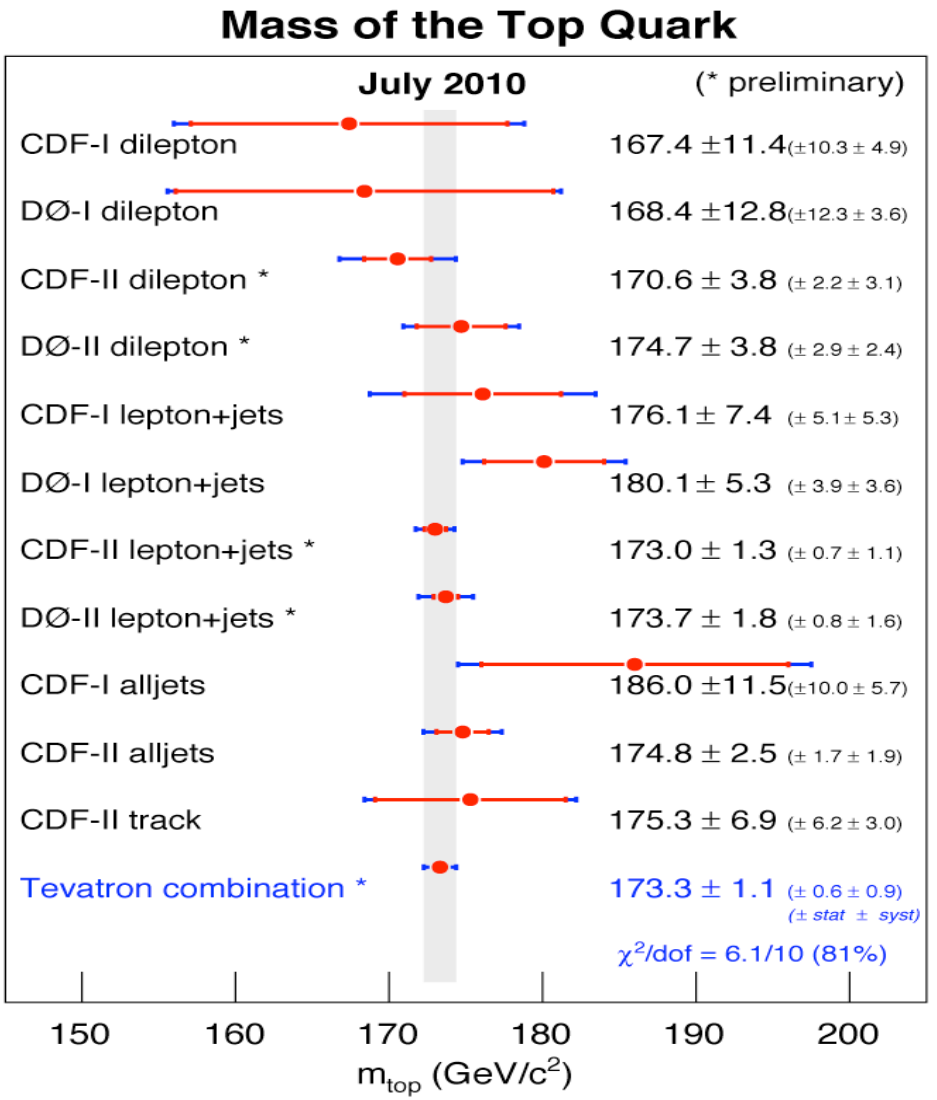
Tevatron

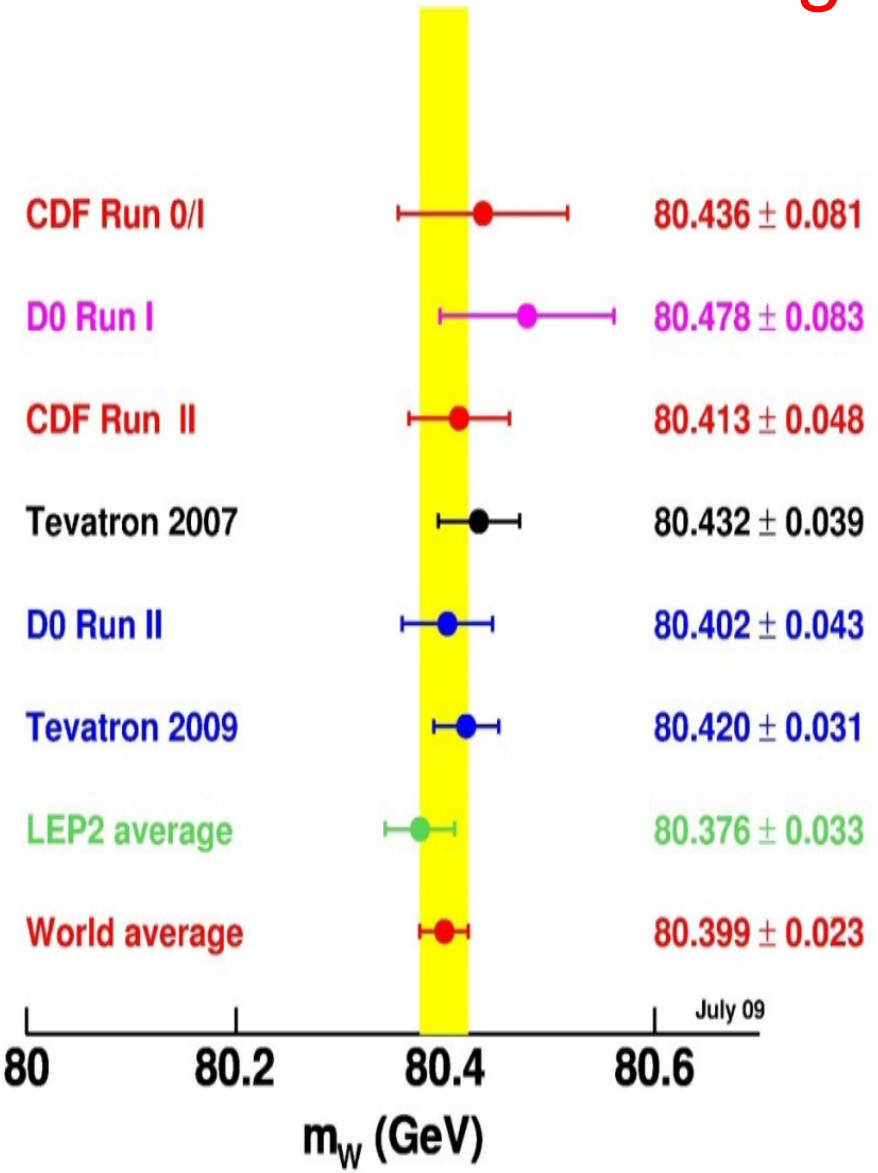
proton-antiproton collisions at 2 TeV



Tevatron's Path to Higgs

Precision physics: excellent detector understanding





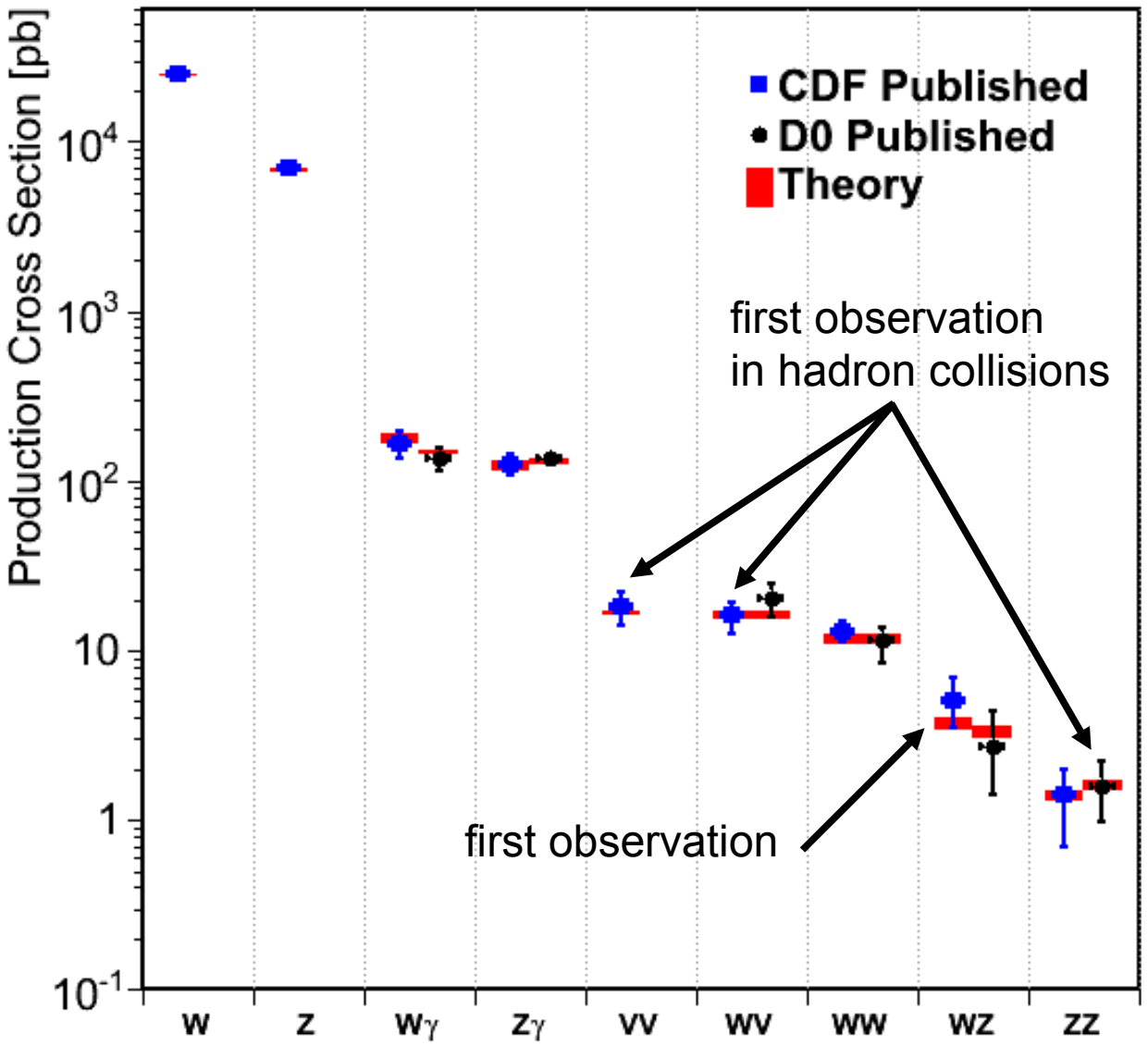
Tevatron's Path to Higgs

Single and diboson production

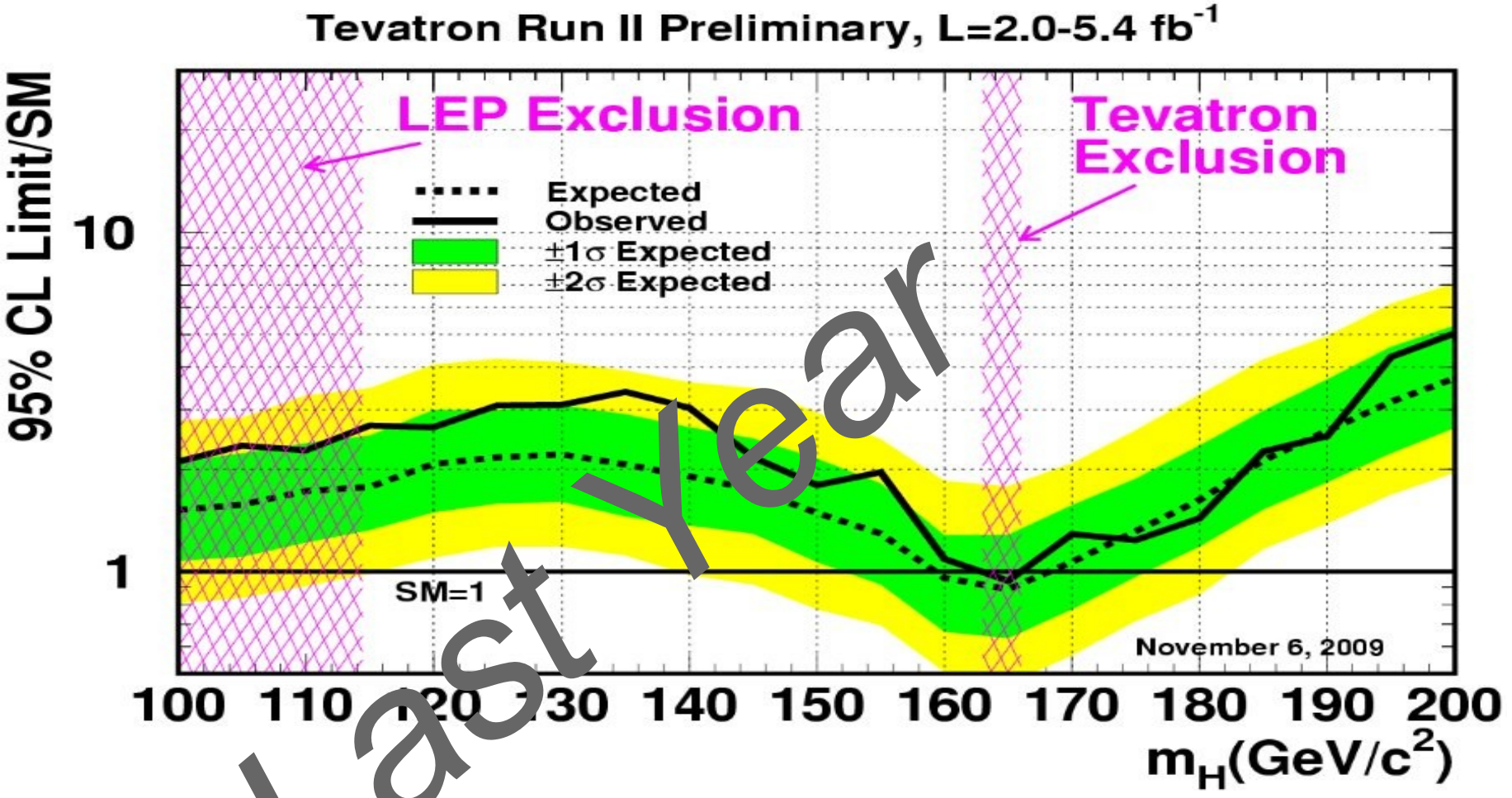
- bosons are key

for Higgs decays

- rare processes
- backgrounds



Tevatron Higgs Exclusion

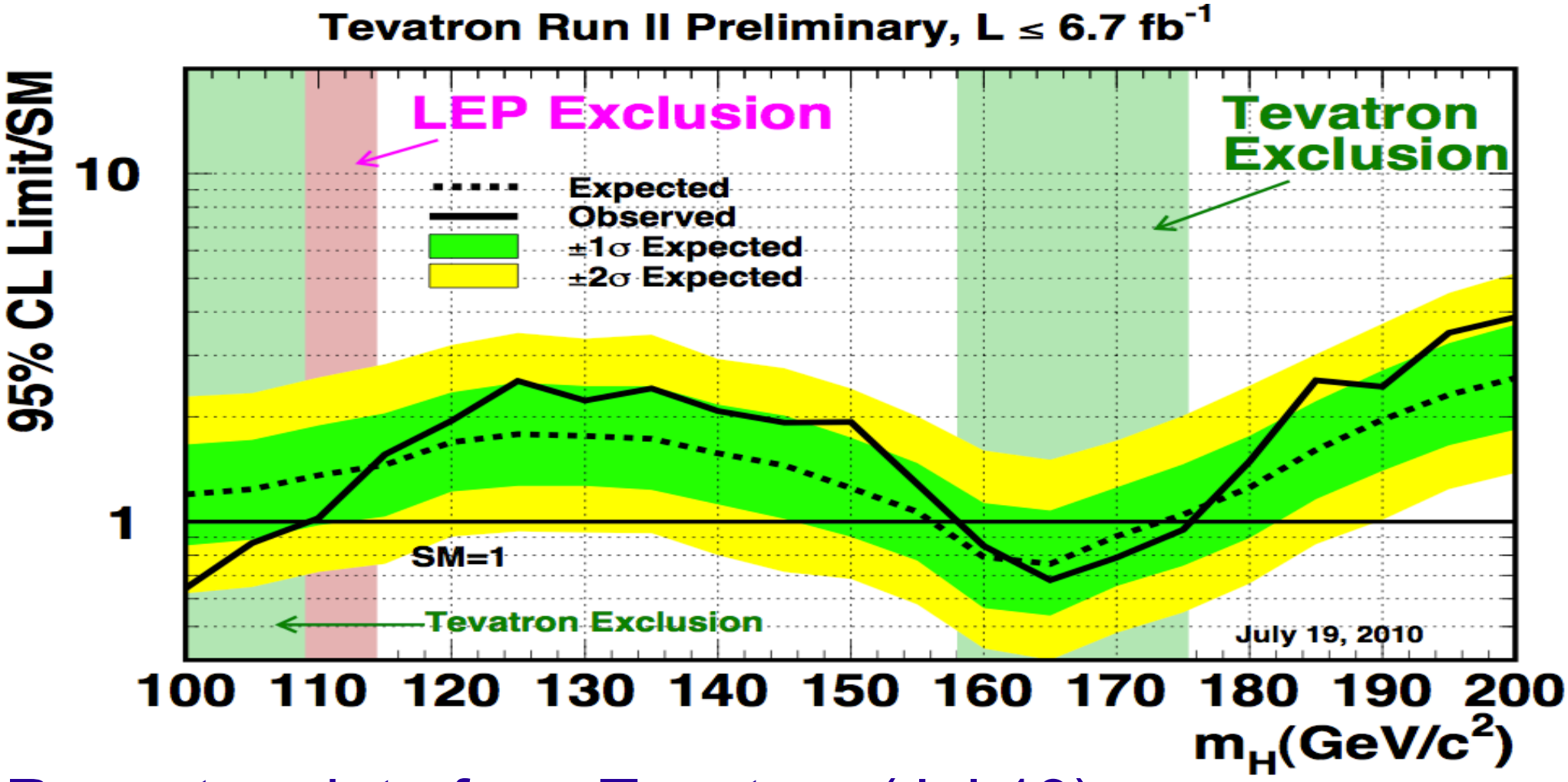


Last Year

Recent update from Tevatron (Nov 6)

- new limit at 95% CL: 163 GeV – 166 GeV excluded
- slightly worse than before but compatible with expectation
- bottom line: additional data were less lucky than initial

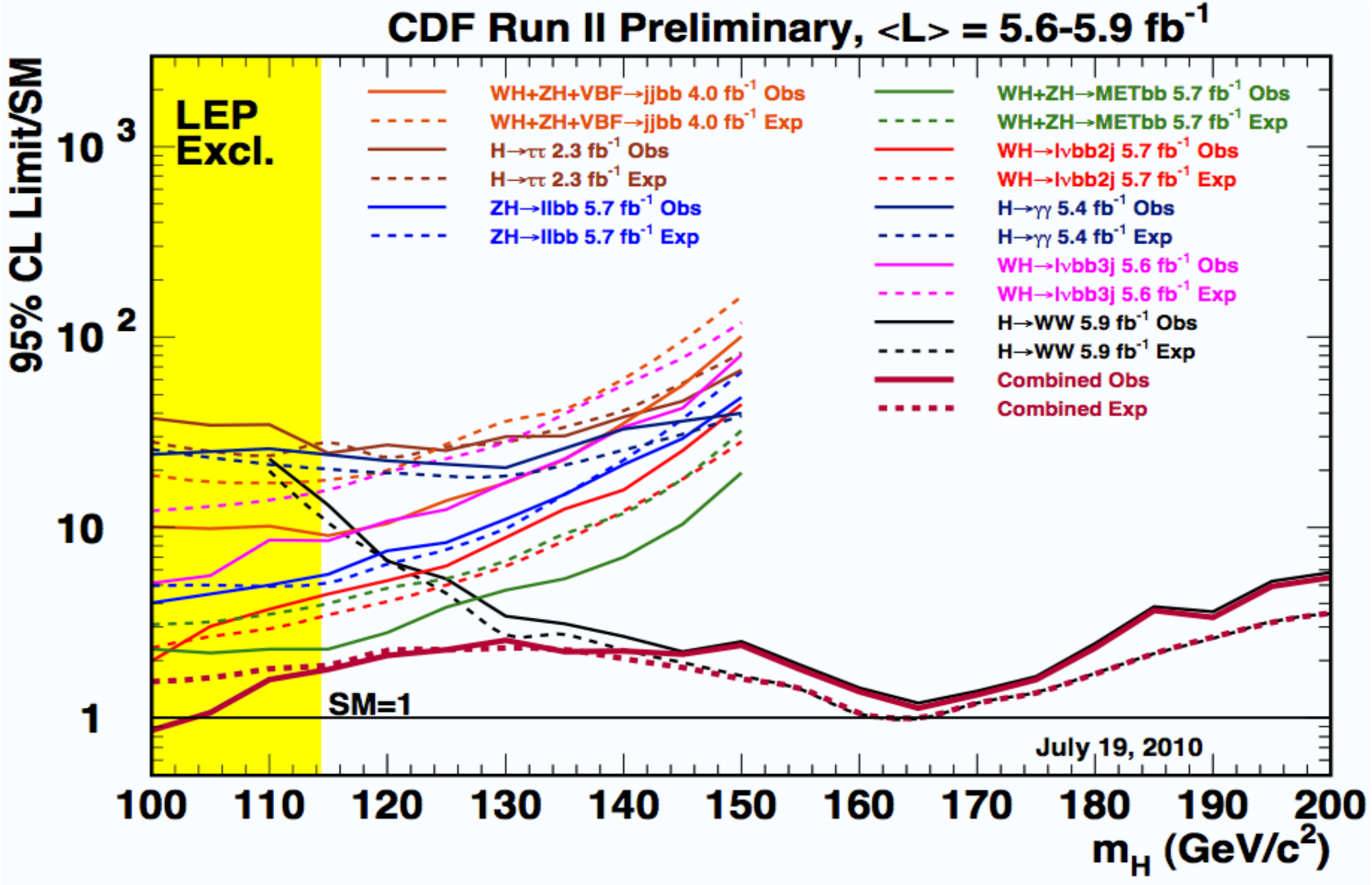
Tevatron Higgs Exclusion



Recent update from Tevatron (Jul 19)

- new limit at 95% CL: 158 GeV – 175 GeV excluded
- mildly worse than expected moving into interesting area
- 'no channel left' behind policy implemented

No channel left behind – Example CDF



What is the Future at the Tevatron?

Motivated by

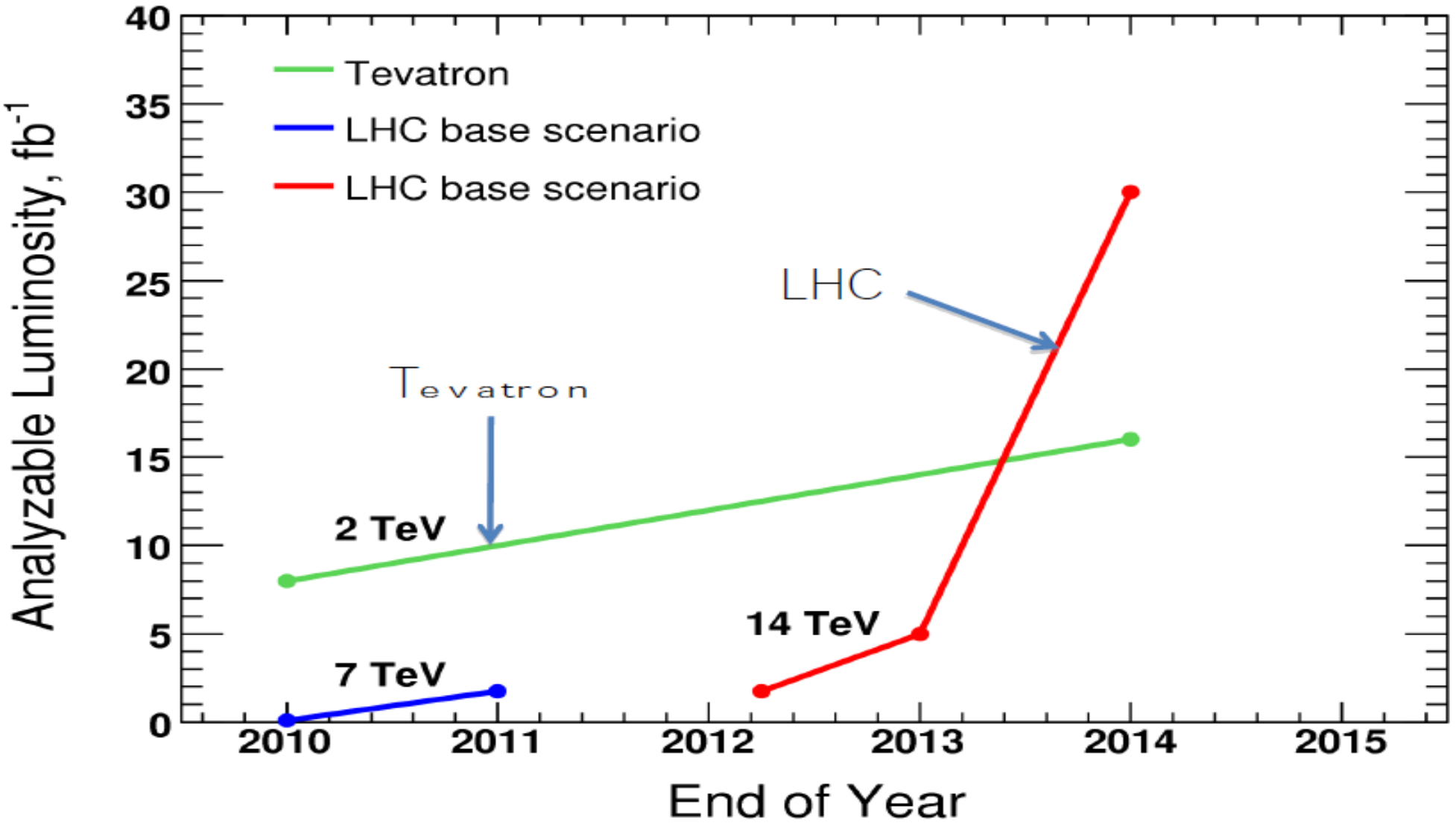
- excellent Tevatron performance
- ever improving Higgs search performance
- and the early LHC schedule (slower than anticipated)

Proposal for Tevatron extension to run until 2014

- P5 discussion Oct 15-16
- '11 Tevatron shutdown: based on expected LHC startup

Year	Collected	Analyzed	note
now (2010)	8 fb^{-1}	6 fb^{-1}	
2011	12 fb^{-1}	10 fb^{-1}	so far end of running
2014	20 fb^{-1}	16 fb^{-1}	in case extension granted

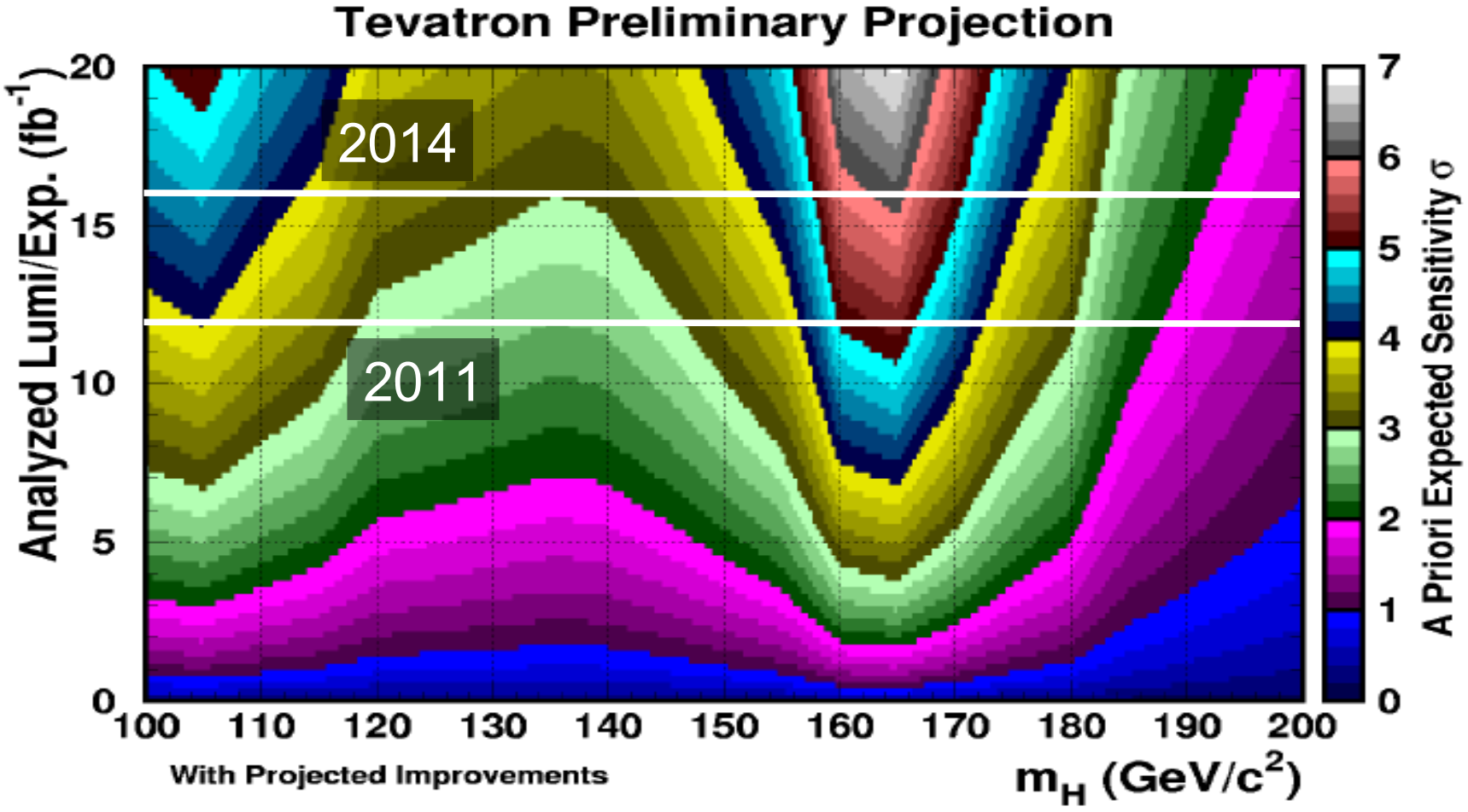
What is the Future at the Tevatron?



LHC schedule since splice issue revealed

– 1 fb^{-1} at 7 TeV,15 months shutdown 2012, restart at 14 TeV

Projected Tevatron Higgs Sensitivity



Tevatron projects for 16 fb^{-1}

- potential for 3 standard deviation 'evidence' in Higgs hot zone
- much better than anticipated

From PAC Review (Oct 15-16)

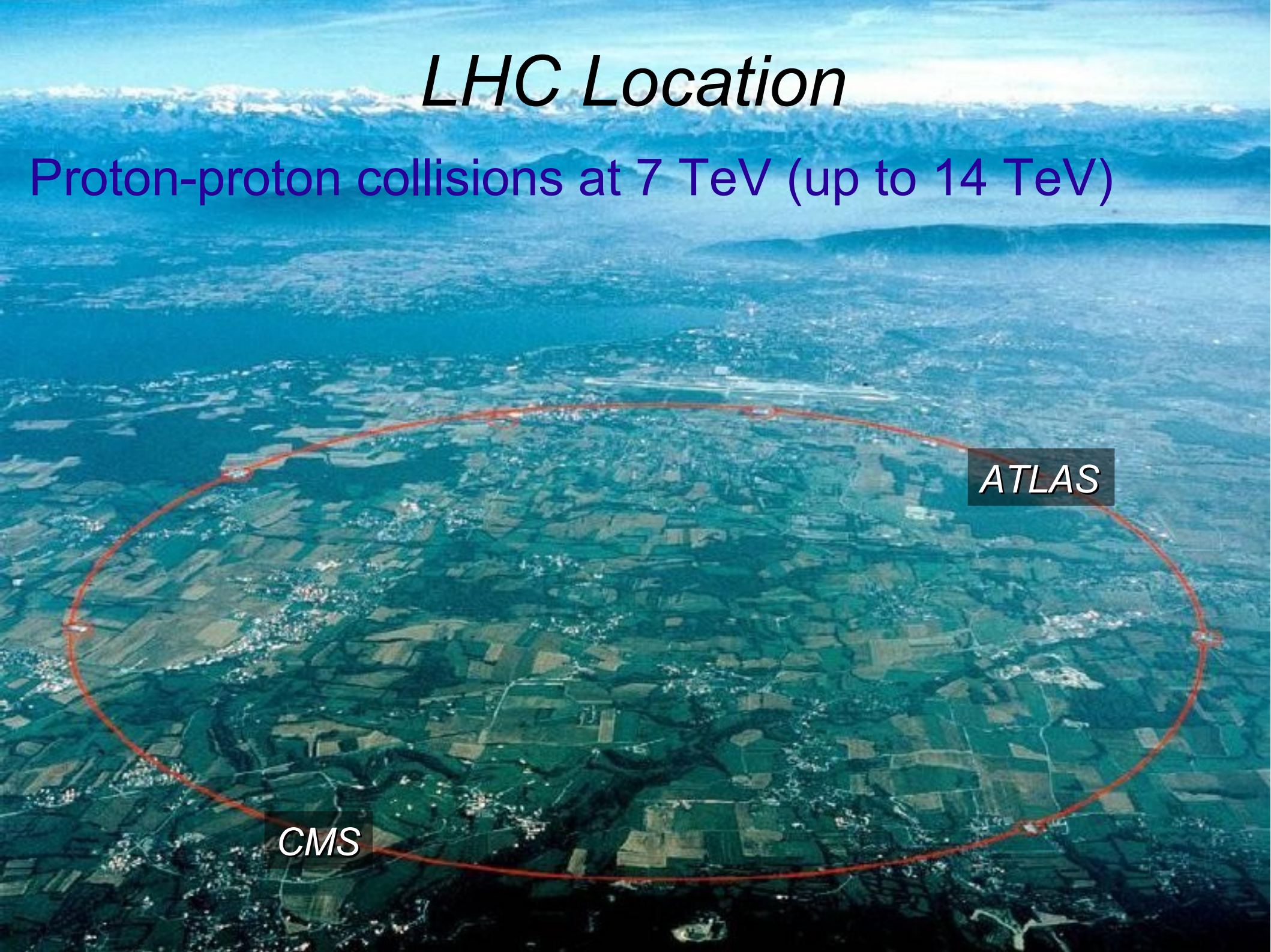
The P5 Panel Recommendation

- Having examined the physics opportunities that an extended Tevatron run would provide as well as the financial strain it would place on the rest of the HEP program, the panel makes the following recommendation:
- **Recommendation 1: The panel recommends that the agencies proceed with a three-year extension of the Tevatron program if the resources required to support such an extension become available in addition to the present funding for HEP. Given the strong physics case, we encourage the funding agencies to try to find the needed additional resources.**

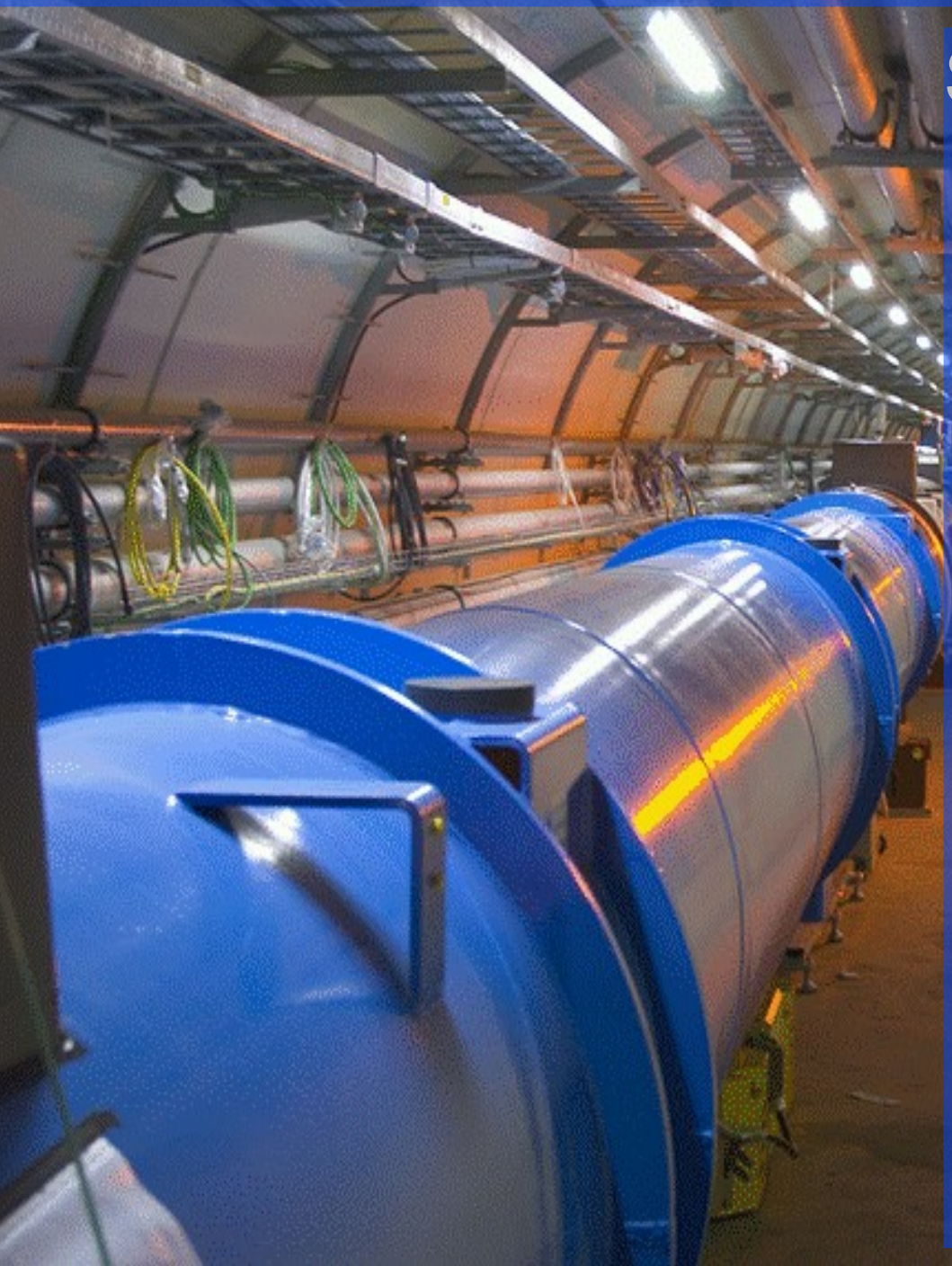
from Baltay's summary slides

LHC Location

Proton-proton collisions at 7 TeV (up to 14 TeV)



LHC Status

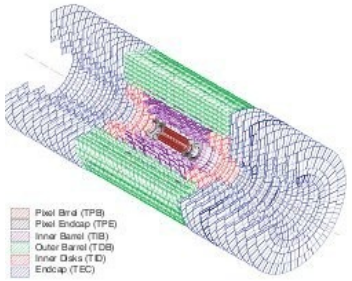


Super short summary

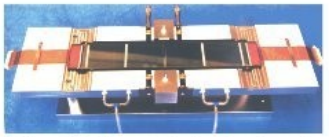
- proceeding with extreme caution
- no show stoppers so far
- nominal bunch intensity reached
- bunch trains commissioned easily
- no beam related quench (as of yet)
- very clean beams
- machine parameters better then expected
- all goals reached

CMS Overview

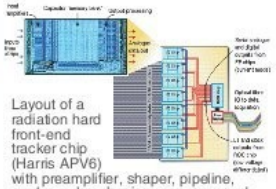
Inner Tracker



The tracking volume is given by a cylinder of a length of 6 m and a diameter of 2.6 m. Fine pitch Si detectors provide precise hits. Pixel detectors placed close to interaction region improve measurement of the track impact parameter and reconstruction of secondary vertices. In the central rapidity region ($|\eta| < 1.5$) the momentum resolution is given by $\Delta p_t / p_t \approx 0.005 + 0.15\, p_t$ (p_t in TeV)

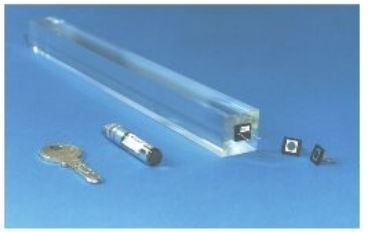


A Si module in its assembly jig. Strips from pairs of 6x6 cm Si detector are bonded together



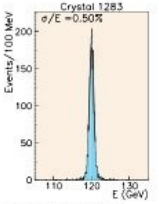
Layout of a radiation hard front-end tracker chip (Harris APV6) with preamplifier, shaper, pipeline, analog pulse shaping processor and multiplexer servicing 128 channels

Electromagnetic Calorimeter

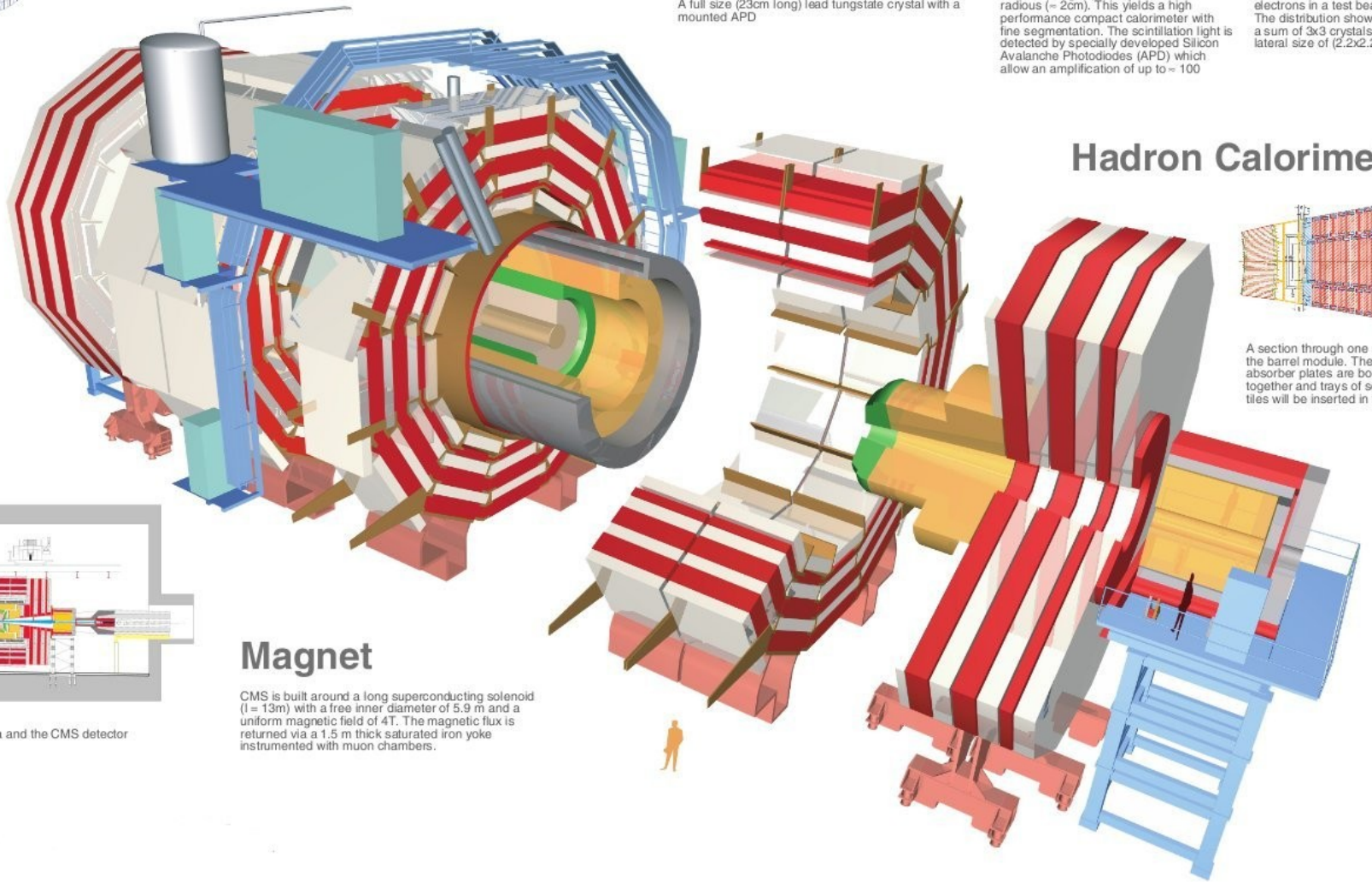


A full size (23cm long) lead tungstate crystal with a mounted APD

Lead tungstate crystals have a short radiation length (0.9cm) and Moliere radious (≈ 2cm). This yields a high performance compact calorimeter with fine segmentation. The scintillation light is detected by specially developed Silicon Avalanche Photodiodes (APD) which allow an amplification of up to ≈ 100



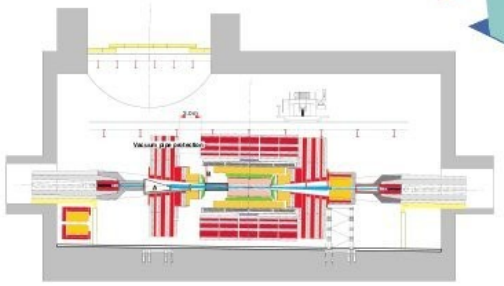
Energy resolution measured with 120 GeV electrons in a test beam. The distribution shown is for a sum of 3x3 crystals with lateral size of (2.2x2.2) cm²



Hadron Calorimeter

A section through one sector of the barrel module. The copper absorber plates are bolted together and trays of scintillator tiles will be inserted in the gaps.

Installation



The underground experimental area and the CMS detector

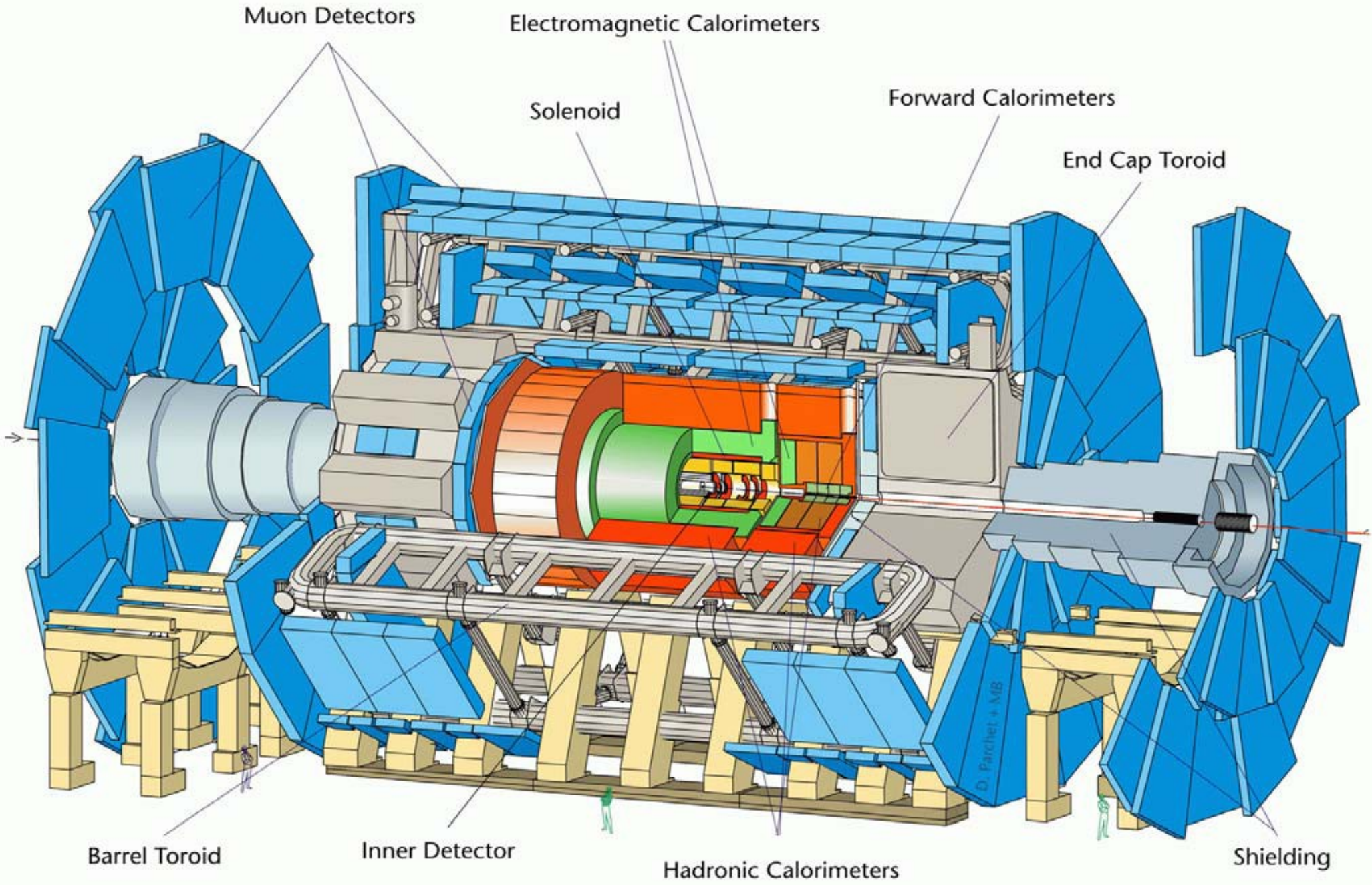
Magnet

CMS is built around a long superconducting solenoid (l = 13m) with a free inner diameter of 5.9 m and a uniform magnetic field of 4T. The magnetic flux is returned via a 1.5 m thick saturated iron yoke instrumented with muon chambers.

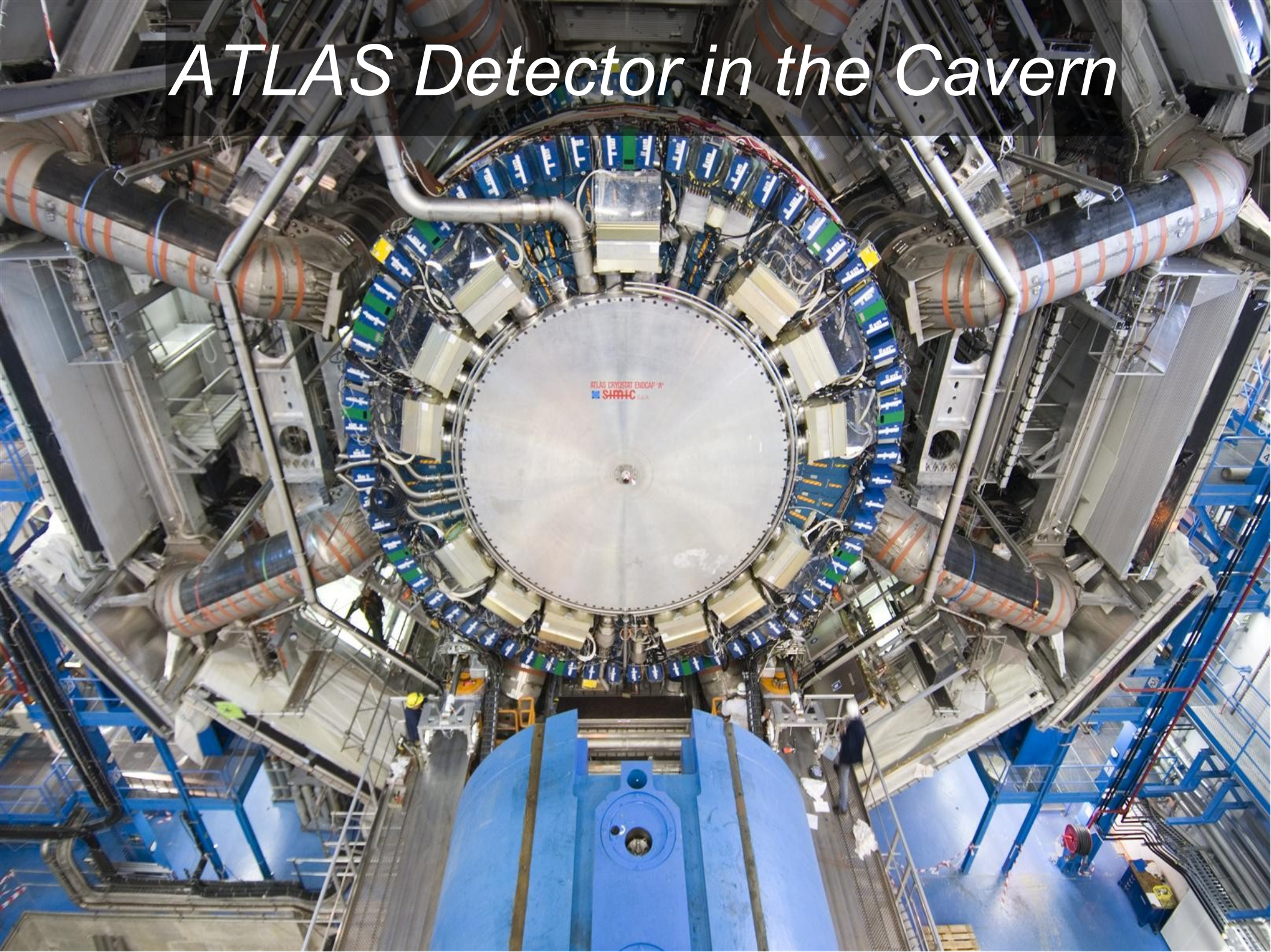
CMS Empty Cavern

CMS Detector in the Cavern

ATLAS Overview



ATLAS Detector in the Cavern



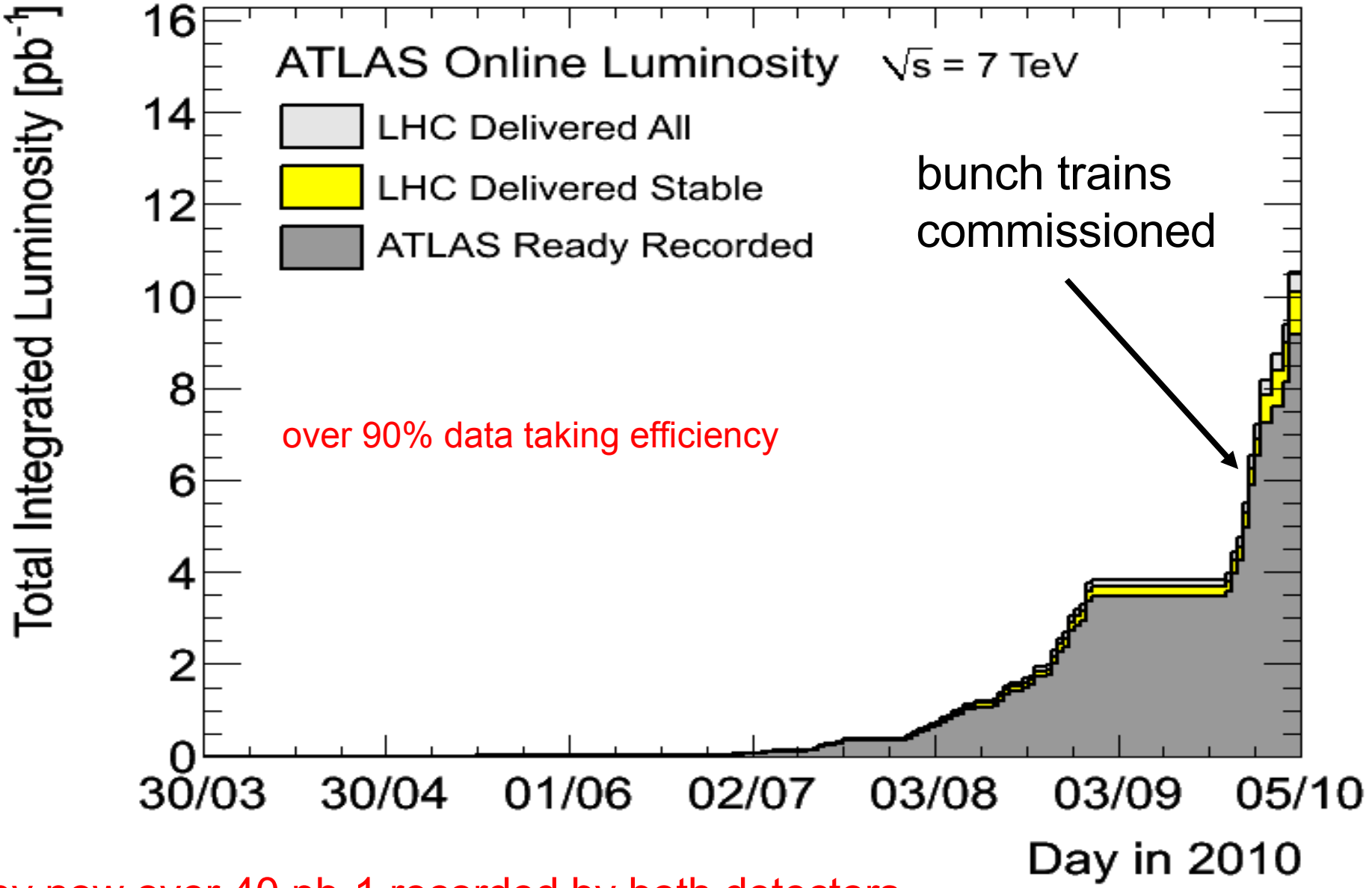
First 'Touching' Protons, CMS

First beams (Nov 20, 2009), ATLAS

Of Course there was Champagne

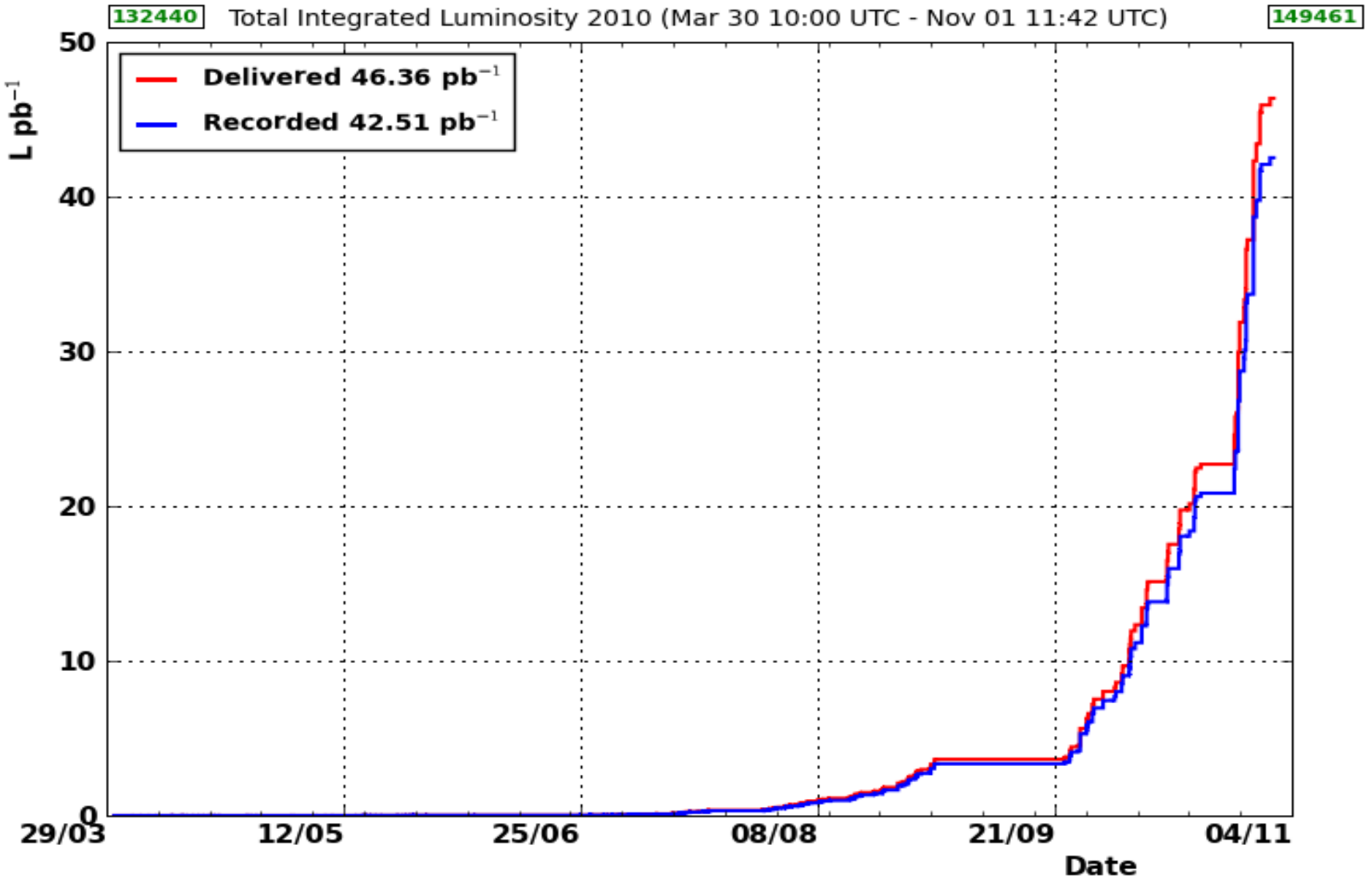
…. remember CMS is on the French side

Taking Data Efficiently, ATLAS

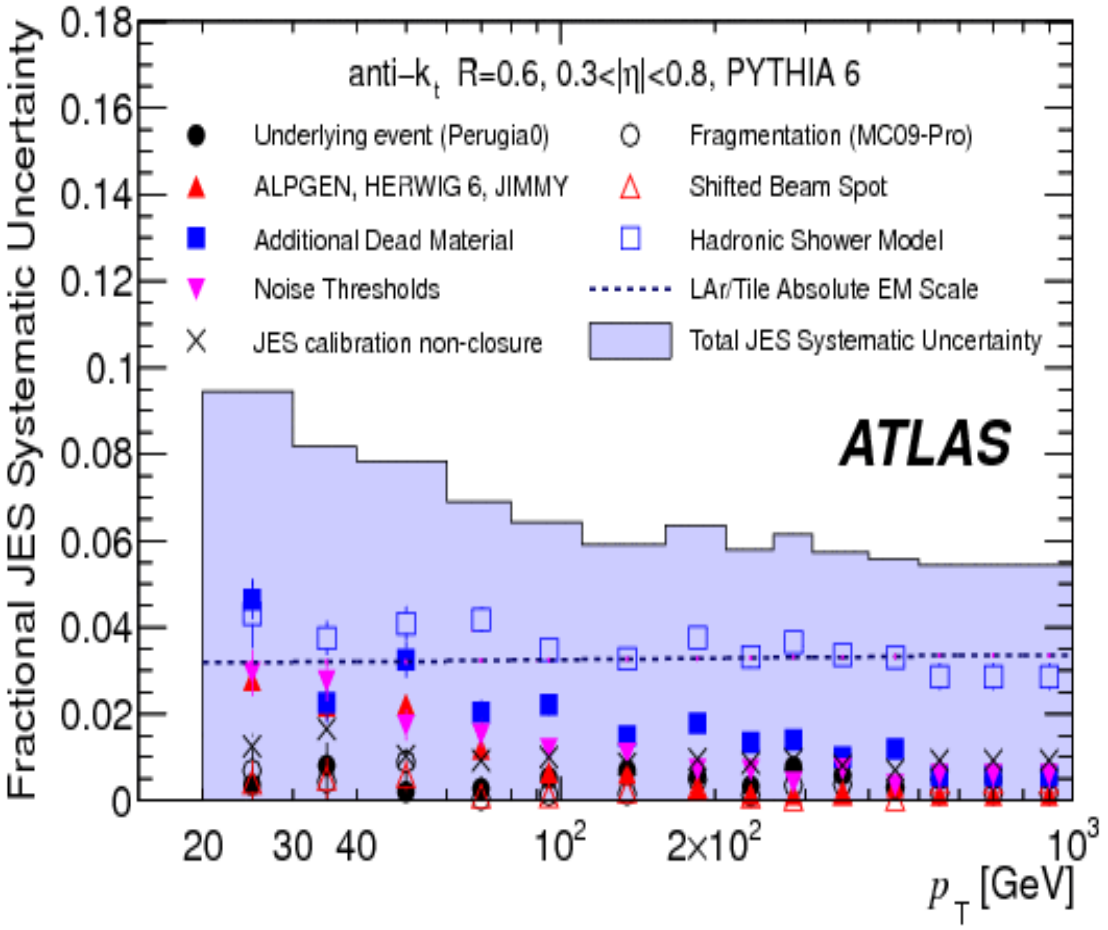


by now over 40 pb-1 recorded by both detectors

Data Accumulated until Today

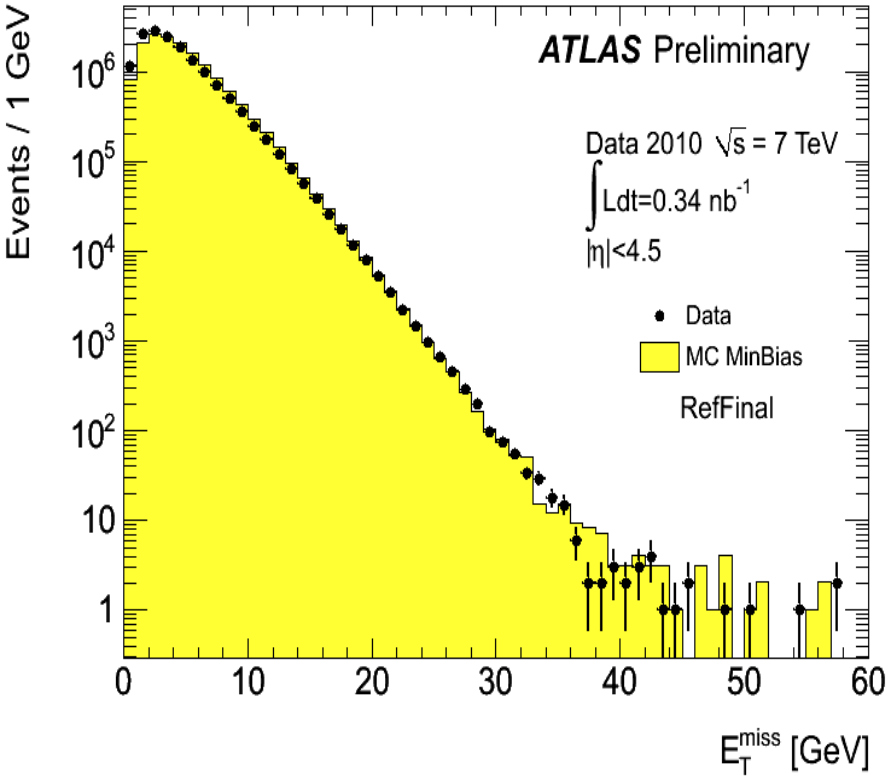


Jet Energy and Missing E_T, ATLAS



Missing energy

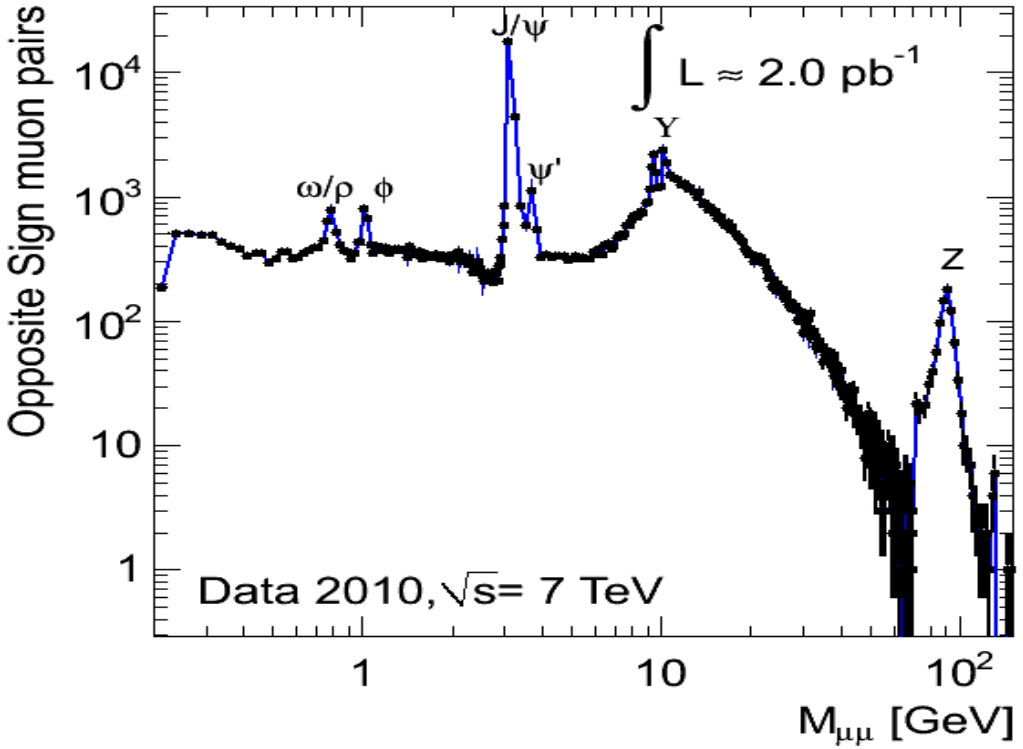
- very well described
- usually takes very long to understand

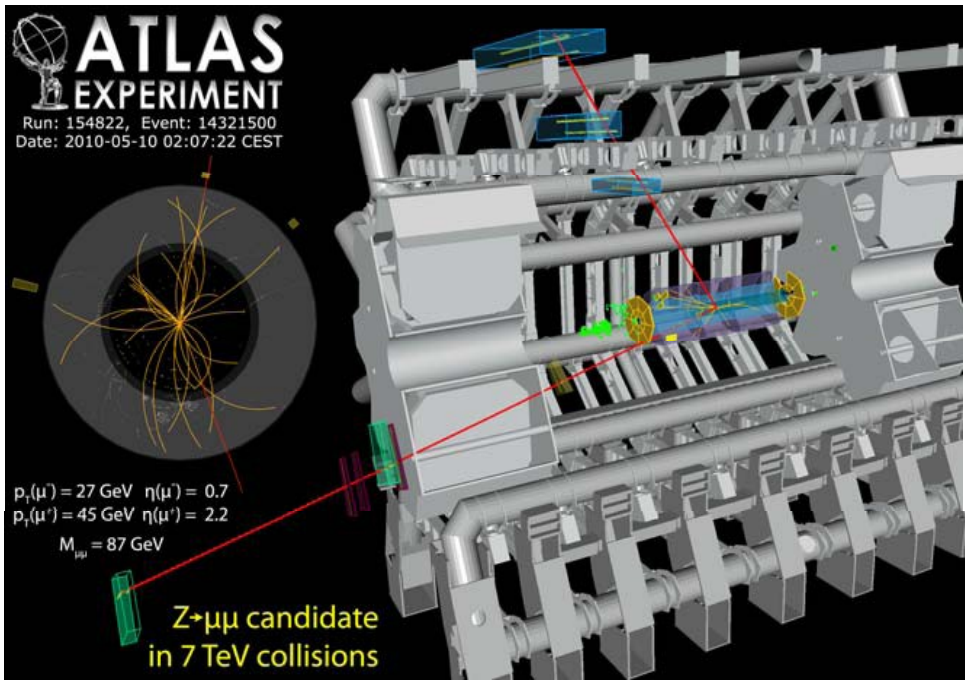


Jet energy scale

- at ~7% uncertainty
- goal is 1%

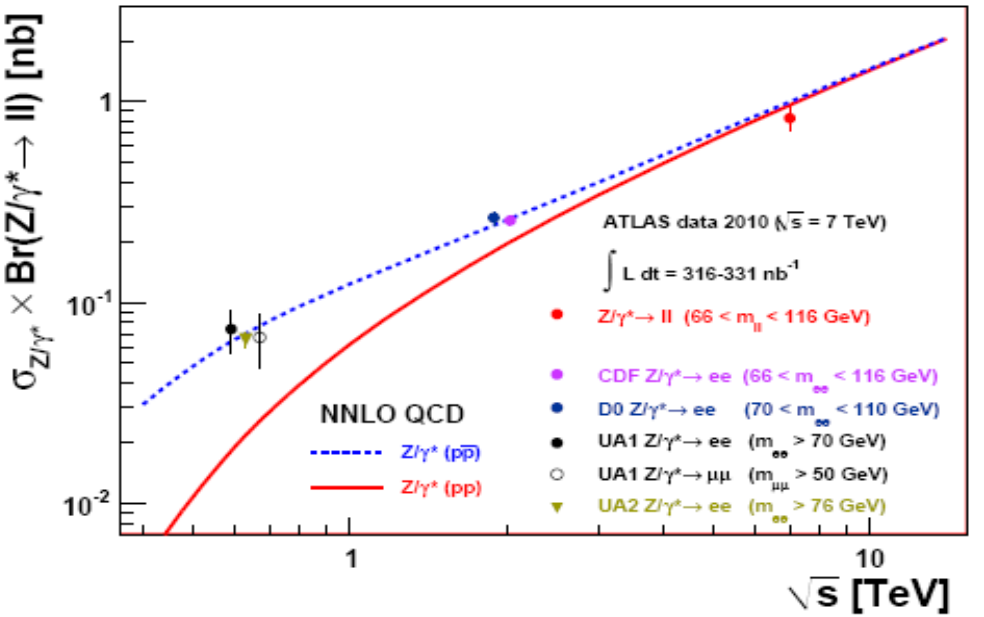
Dimuons, ATLAS





Dimuons in ATLAS

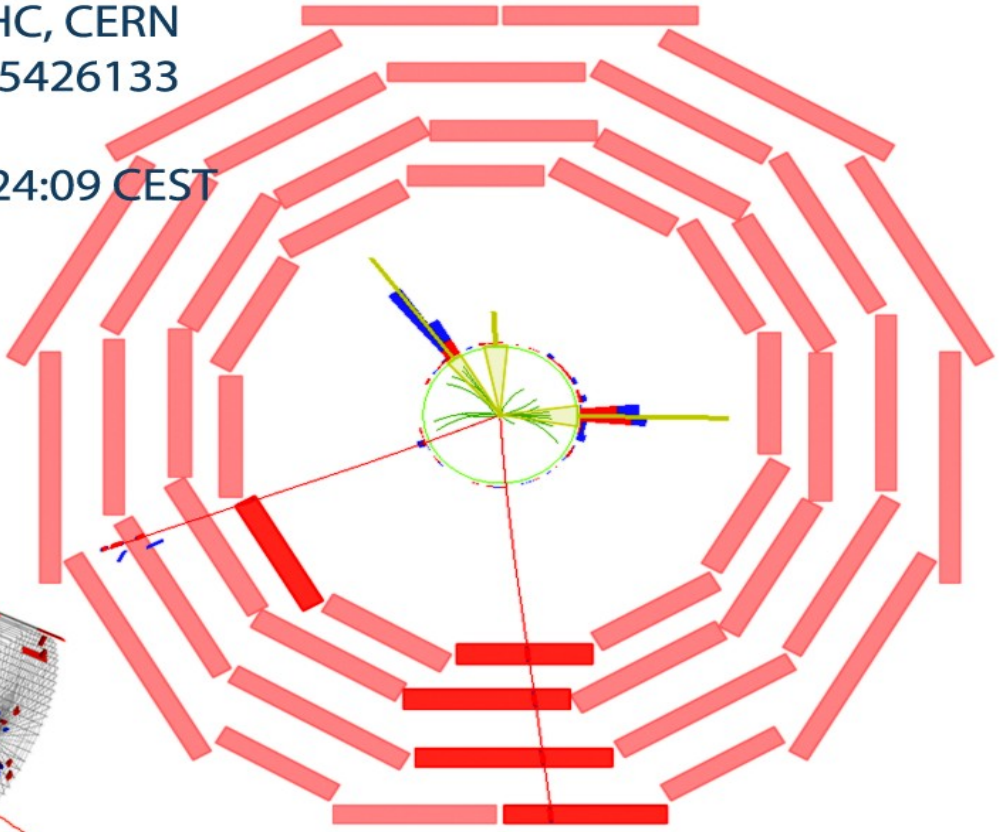
- from ω/ρ to the *Z*
- *beautiful event picture*
- cross section in 0.3 nb-1 published

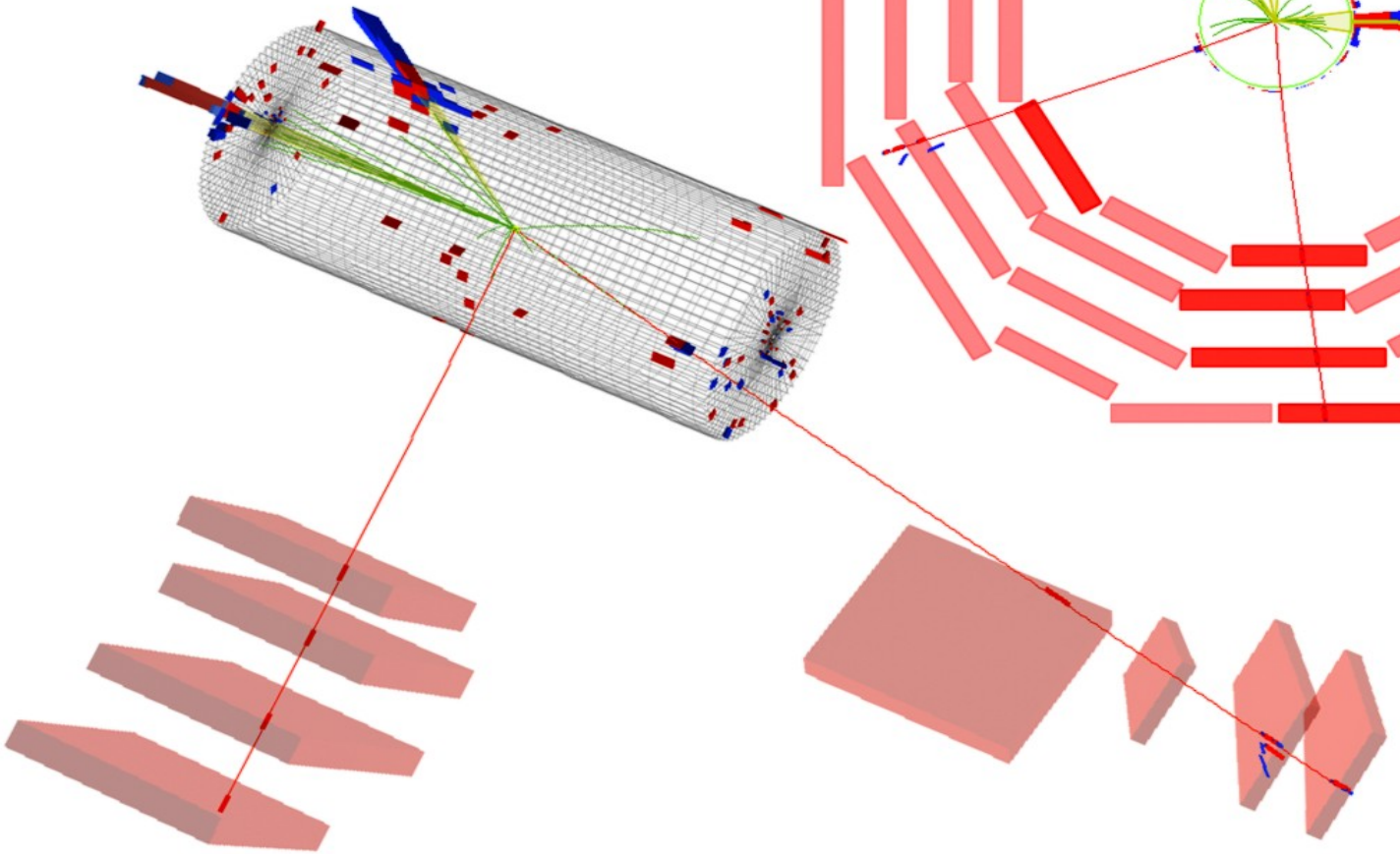


A Dimuon Event, CMS

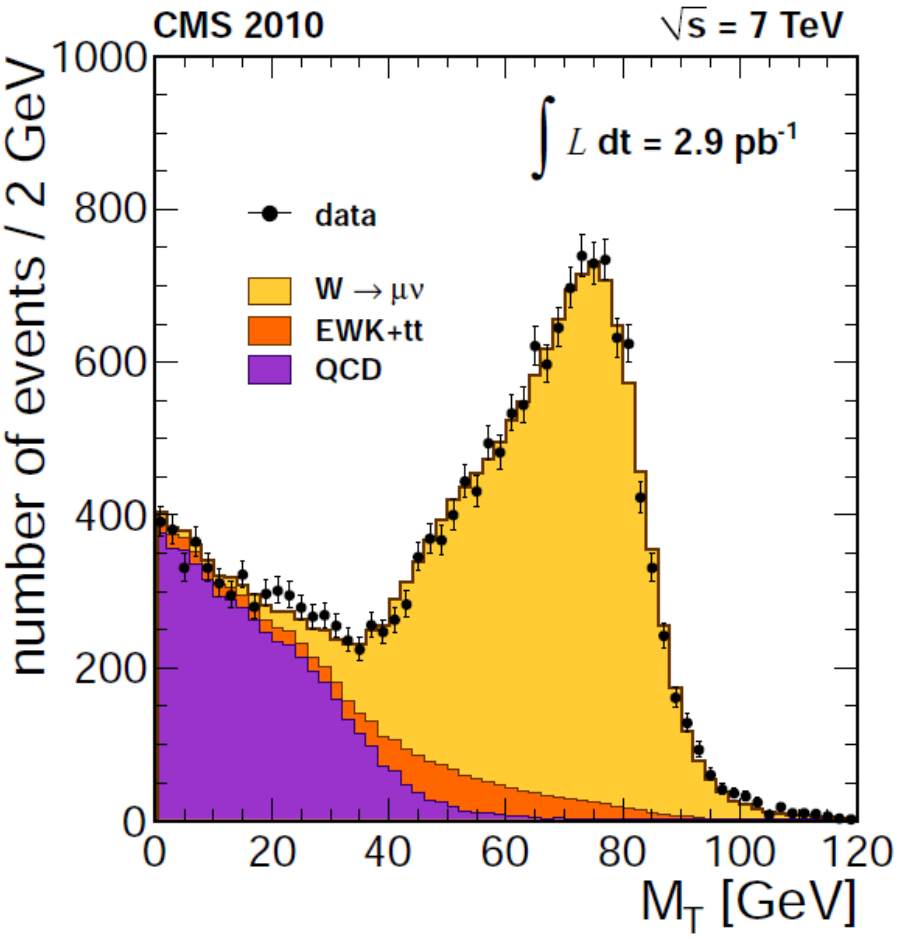
CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

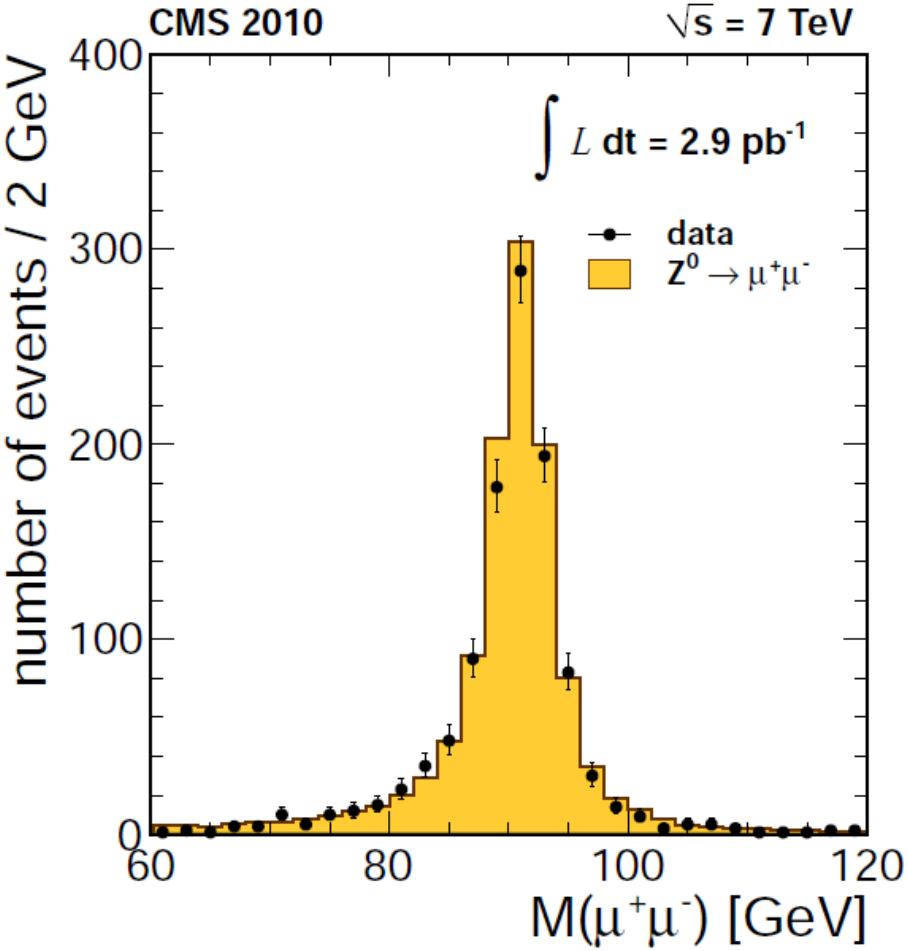
Muon p_T= 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c^2





Muons, CMS



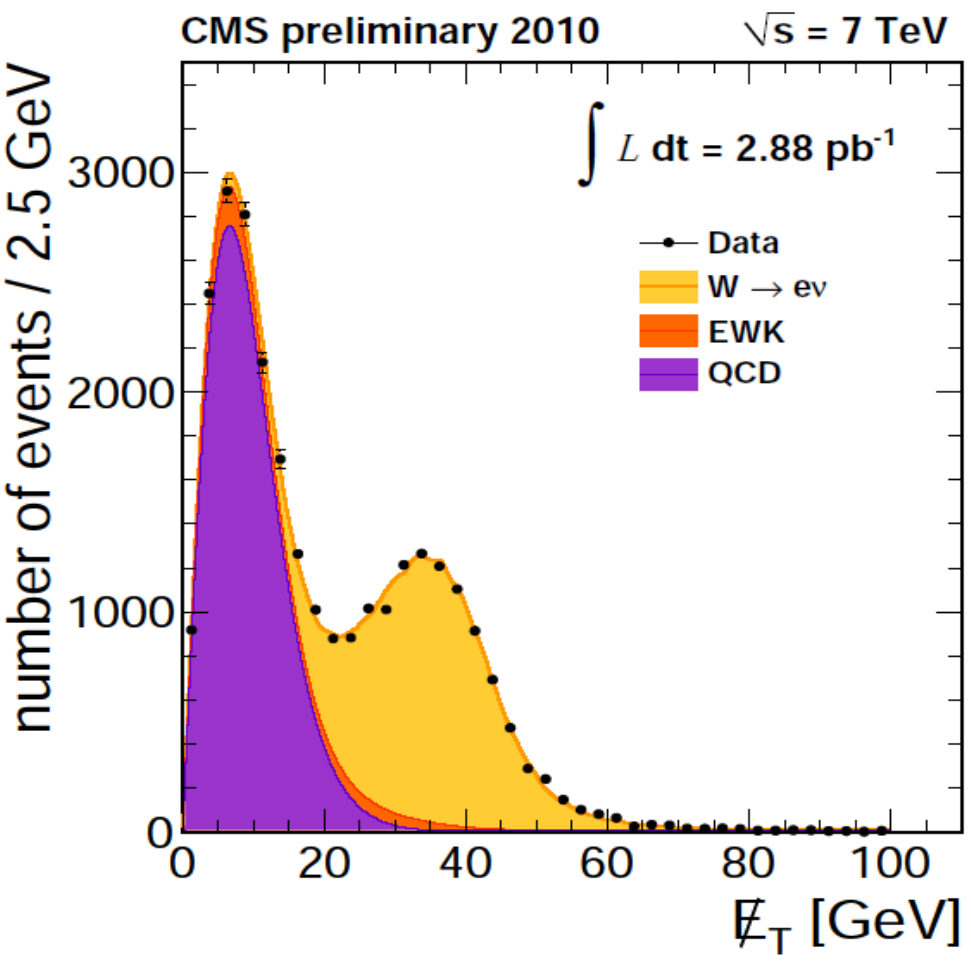


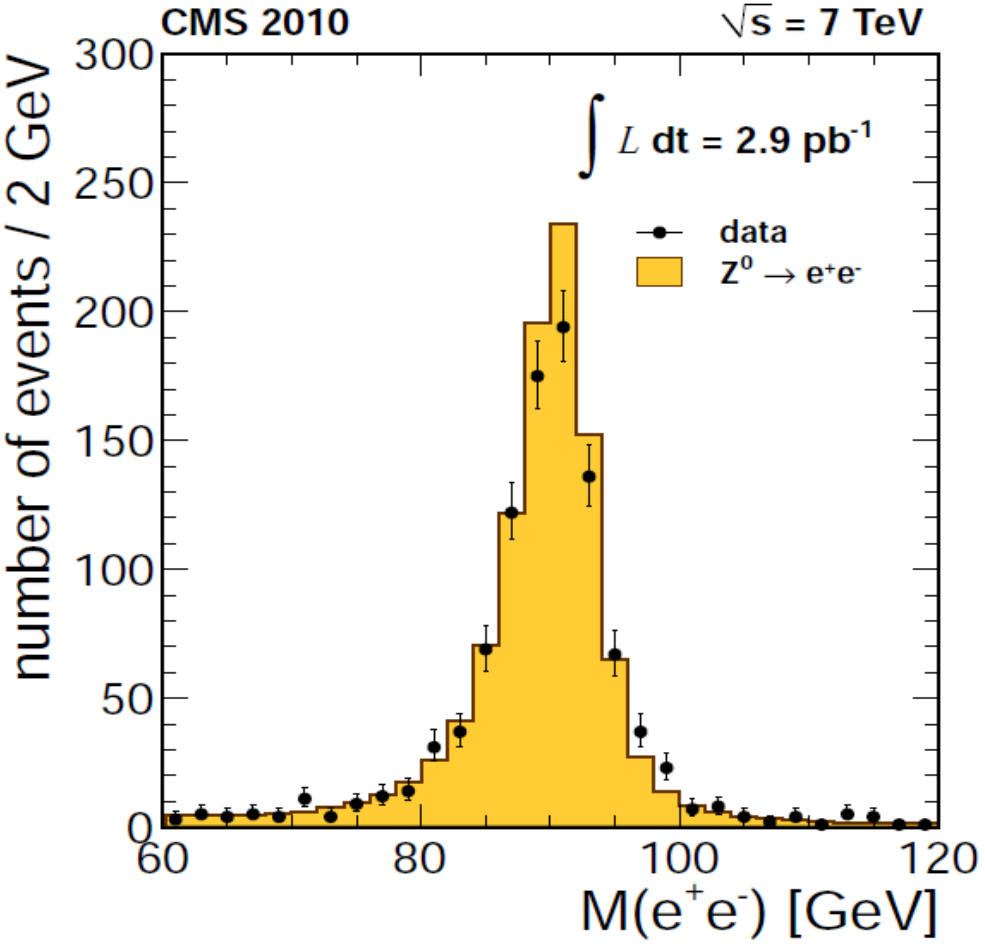
Muons in CMS

- W cross section in 2.9 pb^{-1}
- extremely clean dimuons

publication is under way

Electrons, CMS





Electrons in CMS

- W cross section in 2.9 pb^{-1}
- extremely clean dielectrons

publication is under way

And what is MIT doing on CMS?

You have seen work by Wit, Bolek, Gunther *et al.*

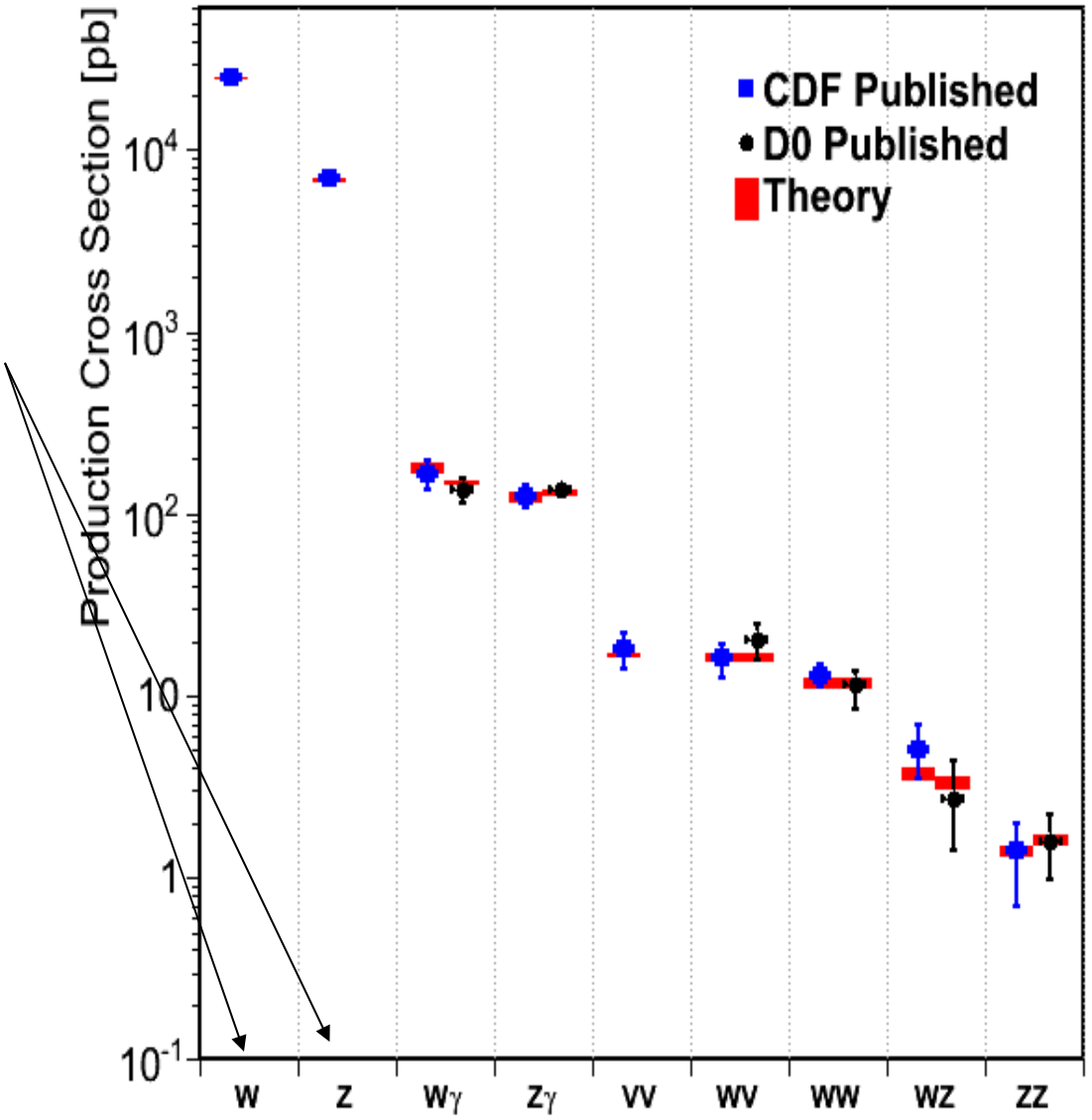
HEP folks: Markus Klute and Steve Nahn

- → coordinated group of students and postdocs
- → Kristian Hahn various pieces and counceling
- → $Z \rightarrow \mu\mu$ (Kevin Sung)
- → $Z \rightarrow ee$ (Si Xie)
- → $W \rightarrow \mu\nu$ (Philip Harris)
- → $W \rightarrow e\nu$ (Pieter Everarts)
- → W+/- asymmetry (Josh Bendavid)
- → all results are about to be published

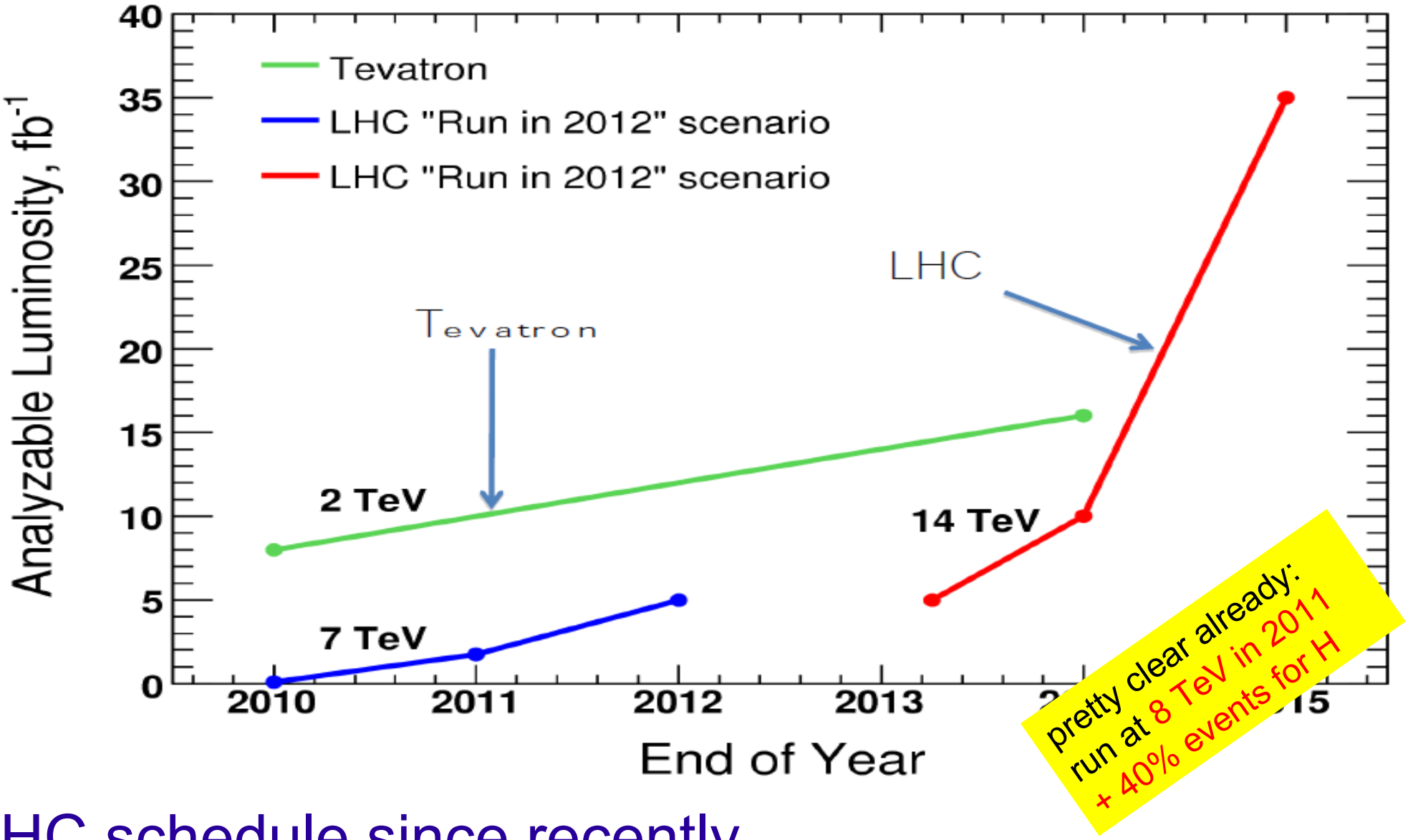
Experiment Status

Detectors work very well

- no show stoppers
- excellent understanding
- first measurements out
- *W*, *Z* as example
- *Wγ*, *Zγ*, *WW* in 'hand'
- ways to go, but lumi is rolling in
- others dibosons will follow very soon
- should be ready to do Higgs searches
- first results for Winter?



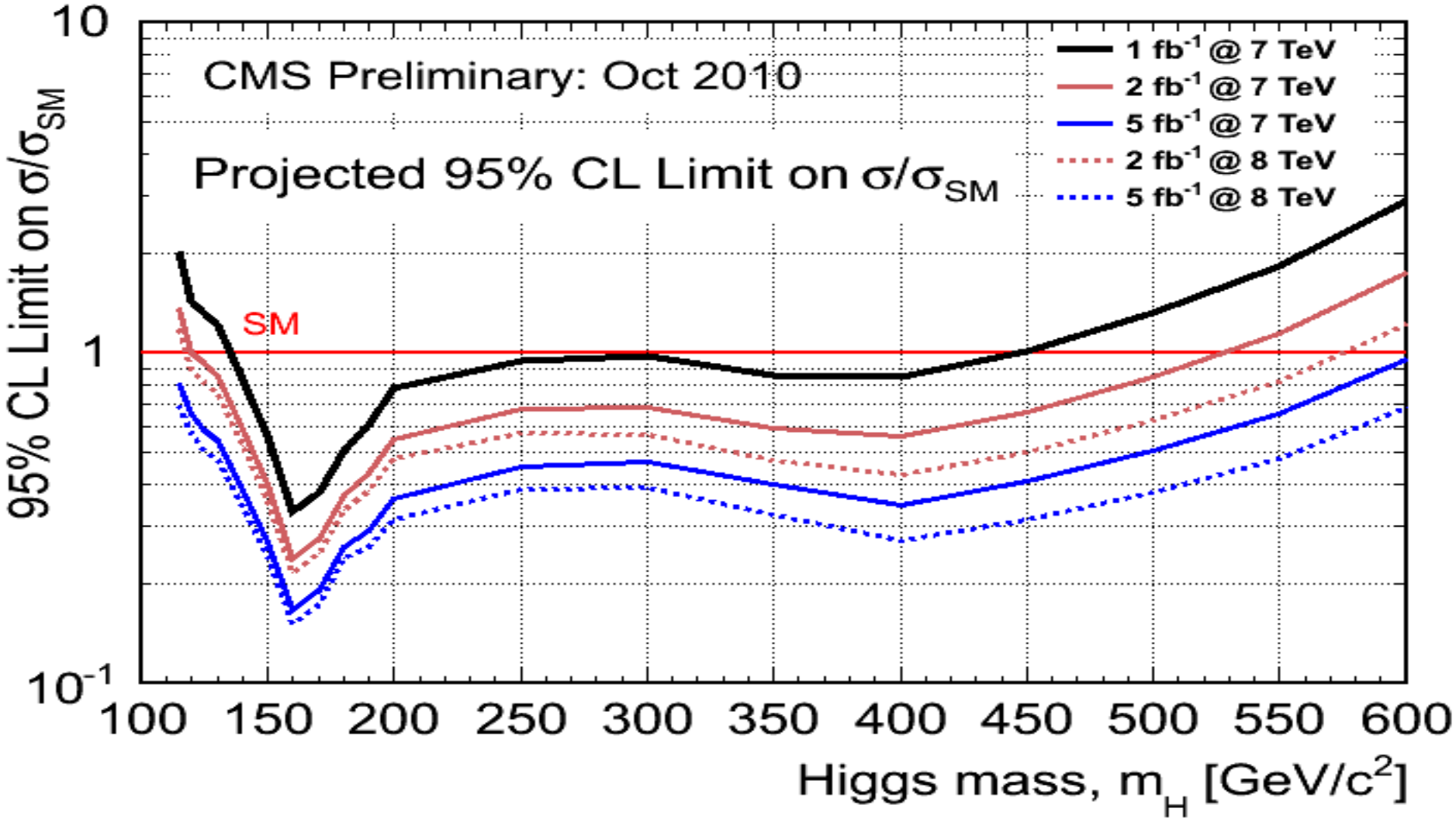
What is the Future at LHC?



LHC schedule since recently

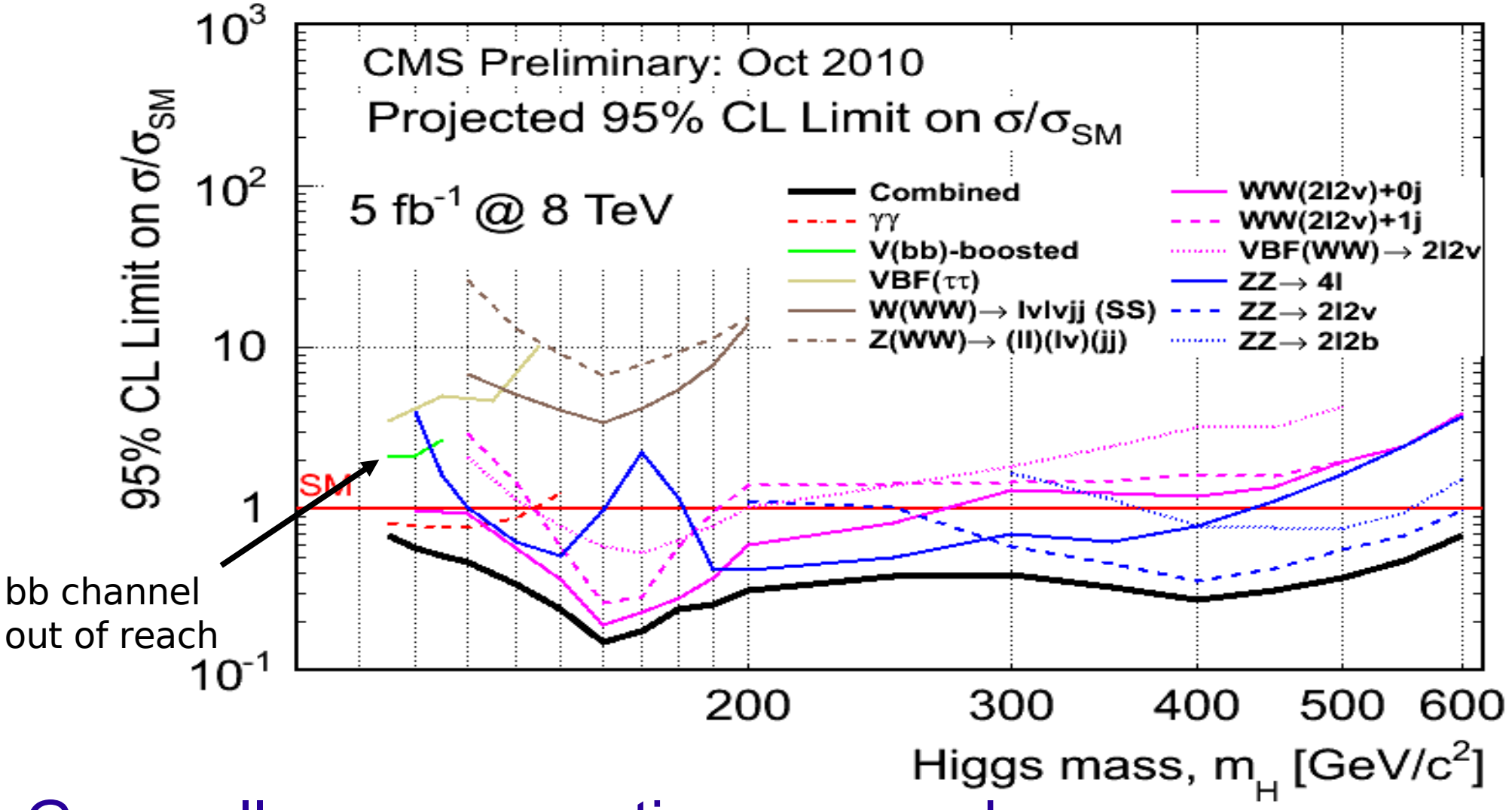
- 5 fb^{-1} at 7 TeV in 2012, before going to 14 TeV?

CMS/LHC Exclusion



	1 fb^{-1} @ 7 TeV	5 fb^{-1} @ 8 TeV
CMS exclusion sensitivity for m_H:	135 – 450 GeV	114 – 600 GeV
ATLAS+CMS (2 x CMS):	120 – 525 GeV	

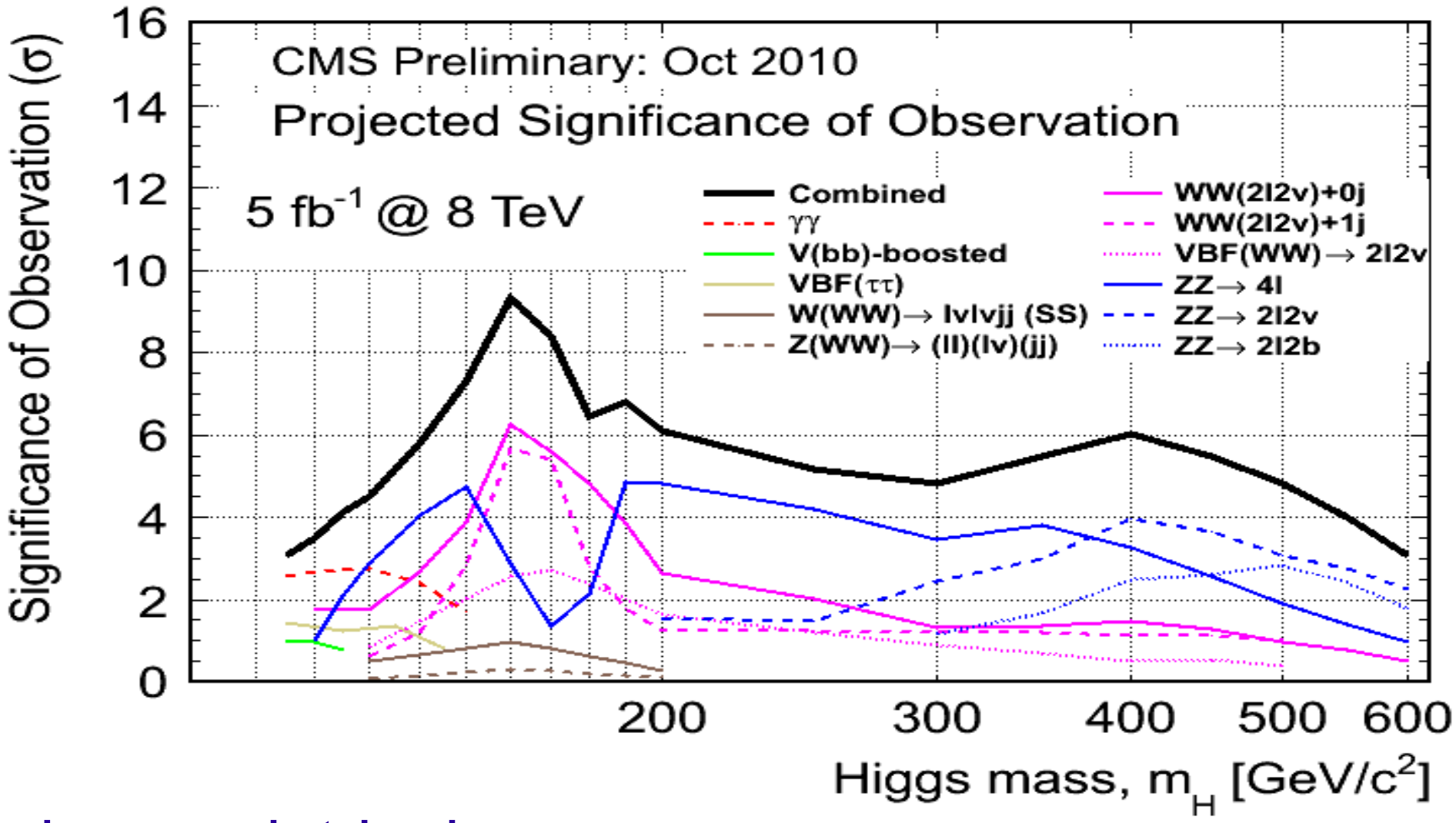
Prospects Exclusion – Example CMS



Generally a conservative approach

- not all possible channels, cut and count based analyses
- but data normalization is still missing

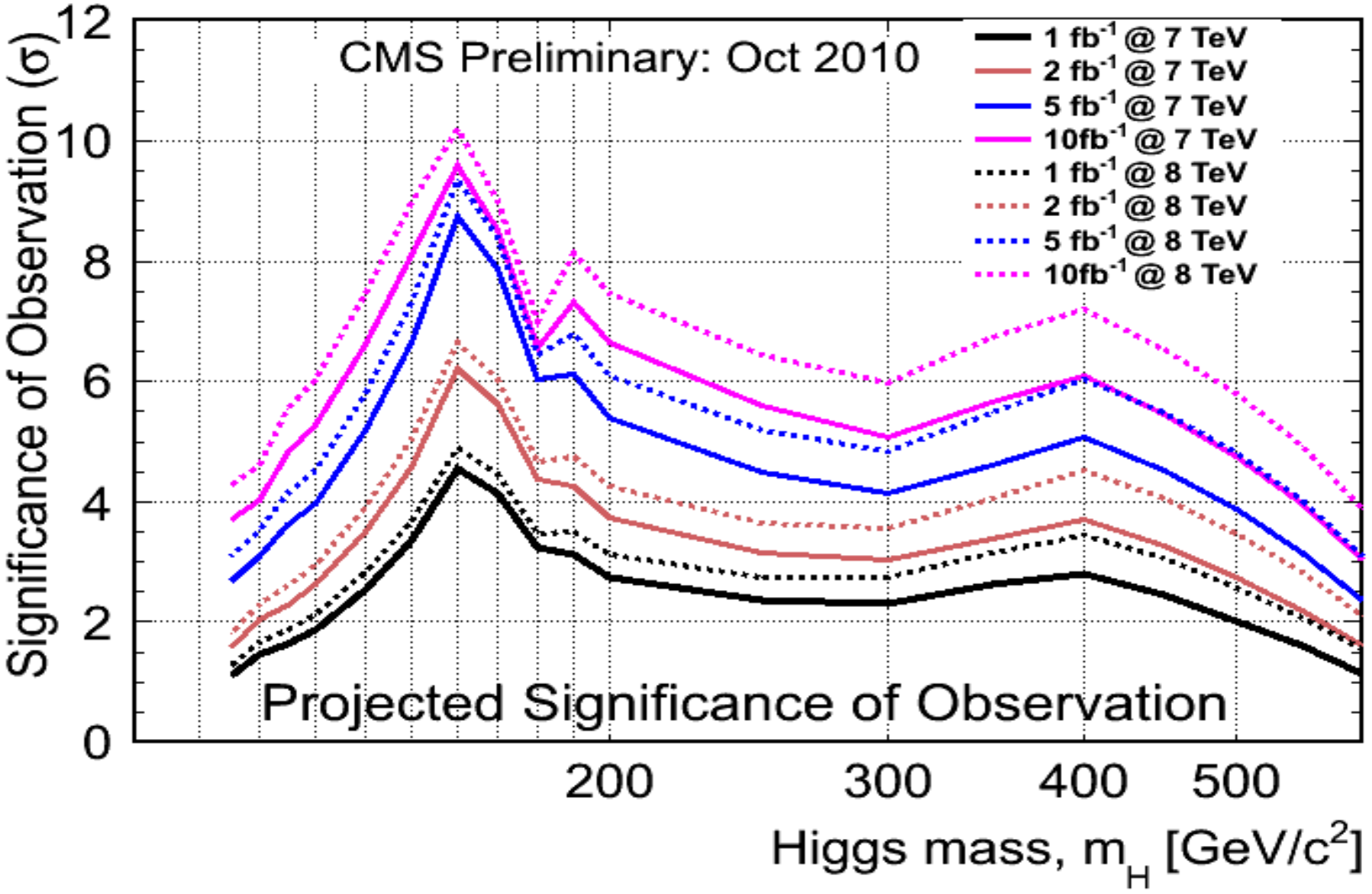
Prospects Discovery – Example CMS



Looks very intriguing

- 3 standard deviations over interesting mass range
- doubling lumi and experiment: discovery seems in sight?!

Prospects Discovery – Example CMS



Indeed: the Higgs is in reach!

Tevatron Complimentarity

Let's assume we have found 'the Higgs'

- first question: is it the Higgs or what else?
- seeing it in various channels helps to constrain properties
- di-fermion decay $H \rightarrow bb$ adds substantial information
- only visible at Tevatron in the beginning

Conclusion

The Tevatron and its experiments

- alive and kicking and reaching for the Higgs
- with 3 more years a three standard deviation 'evidence' possible over entire hot Higgs mass range

The LHC and its experiments

- taking data and doing great
- first measurements are published and more coming
- taking the challenge of the Tevatron, looking into options
- could nail Higgs with in two years, I think we will

Complementary in sensitivity: particular $H \rightarrow bb$

Very exciting times (2 years) are upon us:
Find or exclude the Higgs – Goal since SM exists